



**INTERNATIONAL CRITICAL TABLES**  
**OF**  
**NUMERICAL DATA**  
**PHYSICS, CHEMISTRY AND TECHNOLOGY**  

---

**VOLUME VI**



Tabulation  
001. 4224  
w 2597

# PASTE ON INSIDE COVER

## Key Numbers of Elements

Ag 32	Al 55	As 13	Au 33	B Ba Be Bi Br 54 79 75 15 5					C Ca Cb Cd Ce 16 77 51 29 59					Cl Co Cr Cs Cu 4 44 46 85 31					Dy Er Eu F Fe 67 69 64 3 43					Ga Gd Ge Gl H 25 65 20 73 2					Hf Hg Ho I In 73 30 68 6 26					Ir K La Li Lu 36 83 58 81 72									
Mg 76	Mn 42	Mo 47	N 11	Na Nb Nd Ni O 82 51 61 45 1					Os P Pb Pd 35 12 23 41					Pr Pt Ra Rb 60 37 80 84					Rh Ru S Sa 40 39 8 63					Sb Sc Se Si Sn 14 56 9 18 22					Sr Ta Tb Te Th 78 52 66 10 24					Ti Tl Tm U V 19 27 70 49 50					W Y Yb Zn Zr 43 57 71 23 21				

Car



# ERRATA

## VOLUME I

PAGE

- 103 **THE CRYSTALLINE STATE.** Specific heat. *For* 1 joule = 4.185 cal *read* 1 cal = 4.185 joule.
- 104 Column headed *A*, line *Se*. *For* 1.2 *read* 12.
- 110 Index No. 246. *For* Mol. wt. 118.091 *read* 132.109.
- 194 Index No. 1101. *For*  $\text{CH}_3(\text{C}_3\text{H}_7)\text{CH}_2\text{NH}_2$  *read*  $\text{CH}_3(\text{C}_2\text{H}_5)\text{CHNH}_2$ .

PAGE

- 215 Index Nos. 2387 to 2394. *Add note:* For more accurate data, see 1, **51**: 1544; 29.
- 240 Index No. 3993. Column headed *d*. *Add:* At 0°C.
- 295 *For* Isohydroxydimethylurea *read* Isohydroxydimethyluric acid.
- 306 *After* -5: *delete* 46. *After* 2: *insert* 46.

# ERRATA

## VOLUME II

PAGE

- 167 Last line. *Transpose* 27.2 *from* fourth *to* third column *under* CO.
- 340 Line at head of table. *Add:* For temperature = 17.5°C.
- 415 Diagram for Na-Pb. *Add literature reference:* Calingaert and Boesch, 1, **45**: 1901; 23.

PAGE

- 418 Zn-Sn-Bi and Pb-Sn-Bi diagrams. *Add note:* For best values of the binary eutectics, see the binary diagrams, p. 414 and p. 416.

# ERRATUM

## VOLUME III

PAGE

- 20 O.—*For* 1.447 at the B. P. *read* 1.1447.

# ERRATA

## VOLUME IV

PAGE

- 166 Index No. 1826. At 54.0°C *for* 51.8 *read* 58.1 Wt. % A.
- 242 *For*  $\text{K}_2\text{SO}_4 \cdot \text{Cr}_2(\text{SO}_4)_3$  *read*  $\text{KCr}(\text{SO}_4)_2$ .
- 248 Literature citation (**175**). *For* 01 *read* 00.

PAGE

- 470  $\text{C}_8\text{H}_{18}\text{O}$ , Octyl alcohol. *For* column head M/g  $\text{H}_2\text{O}$  *read* M/kg  $\text{H}_2\text{O}$ .

# ERRATA

## VOLUME V

PAGE

- 54 Second column. CHANGE IN RADIUS WITH TIME. Column 2. *For* Air *read*  $\text{CO}_2$ .
- 80 A-TABLE. Air.  $\gamma$  at -79°C. *For* 3.33 *read* 2.33.
- 93 Literature citations for Ir. *For* (3) *read* Behn, 8, 66: 237; 98 *and for* (85) *read* Violle, 34, 89: 702; 79.
- 113  $\text{H}_2\text{O}$ , Water. In Note: *for* increased *read* decreased *and for* 4.185 cal<sub>15</sub> *read* 1 cal<sub>15</sub> = 4.185 joule.
- 147 **HEAT OF ISOTHERMAL COMPRESSION.** *For* 10<sup>4</sup>Q *read* 10<sup>4</sup>Q.

PAGE

- 248 **SYMBOLS AND NUMERICAL RELATIONS.** Definitions for *k* and *k<sub>g</sub>*. *For*  $\lambda_0$  *read*  $\lambda$ . Definition for *n*. *For*  $\lambda_0/\lambda$  *read*  $\lambda/\lambda_m$ . Column 2, line 15. *For*  $\lambda$  *read*  $\lambda_m$ . Line 16. *For*  $\lambda_0$  *read*  $\lambda$ .
- 249–252 inclusive. Introductions to Tables 1 to 4 inclusive. *For*  $\lambda_0$  *read*  $\lambda$ .
- 358 Literature citation (**458**). *For* 237 *read* 637.
- 388 Figure 1. *For*  $\frac{1}{3}\text{Ca}_2(\text{PO}_4)_2$  *read*  $\frac{1}{3}\text{Ca}_3(\text{PO}_4)_2$ .





# INTERNATIONAL CRITICAL TABLES OF NUMERICAL DATA, PHYSICS, CHEMISTRY AND TECHNOLOGY

Prepared under the Auspices of the International  
Research Council and the National  
Academy of Sciences

BY THE  
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UNITED STATES OF AMERICA

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## VOLUME VI

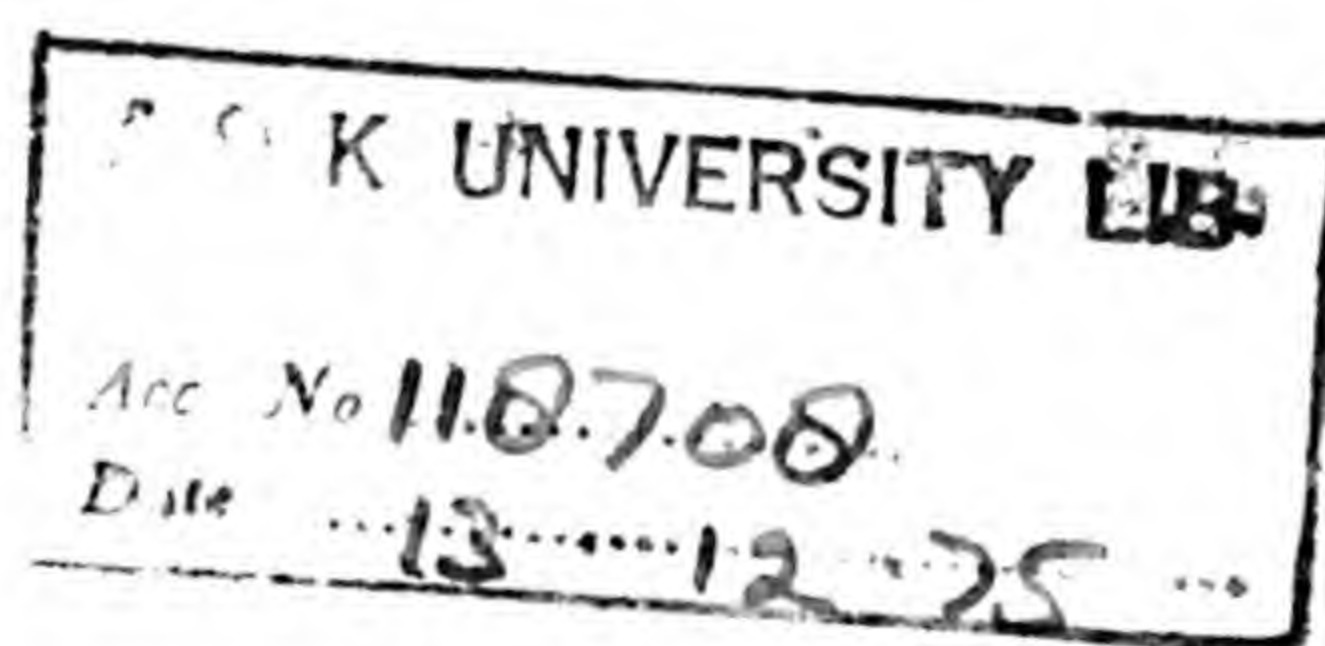
FIRST EDITION

PUBLISHED FOR THE  
NATIONAL RESEARCH COUNCIL

BY THE  
McGRAW-HILL BOOK COMPANY, INC.  
NEW YORK: 370 SEVENTH AVENUE  
LONDON: 6 & 8 BOUVERIE ST., E. C. 4

1929

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## PREFACE TO VOLUMES VI AND VII

At an early stage in the development of the project it became necessary to determine the size of International Critical Tables in order that the requisite financial estimates might be prepared. At that time it was estimated that 2500 pages would suffice, and on this figure the financial requirements of the editorial office and the selling price of the work were based. In the course of the preparation of Volume IV it became apparent that 2500 pages would be insufficient, this being due largely to the phenomenal increase, during the last decade, in the amount of scientific work published.

To the problem thus presented to the Editorial Board only three possible solutions appeared: (1) To eliminate a large proportion of the data in each of the unpublished chapters, thus destroying entirely the completeness aimed for and promised; (2) to omit a considerable number of chapters in order to preserve the completeness of those selected for publication; (3) to expand the publication program to the extent of two additional volumes and to raise the considerable sum of money required to finance the publication of these additional volumes at the same subscription price per volume as the original five. The third solution appeared to be the only logical one.

Through the generous financial support of the Research Corporation, the Chemical Foundation, and the United States Steel Corporation, it has become possible to finance the publication of Volumes VI and VII and thus to carry out the editorial program without sacrifice of completeness.

THE BOARD OF EDITORS.



# COOPERATING EXPERTS—VOLUME SIX

	PAGE
BARKLA, CHARLES GLOVER, D.S., F.R.S., Nobel Laureate: Professor of Natural Philosophy, University of Edinburgh, Edinburgh, Scotland.....	1
BARNETT, S. J., Ph.D.: Professor of Physics, University of California, Los Angeles, California, and Research Associate, California Institute of Technology, Pasadena, California.....	345
BJERRUM, NIELS, Ph.D.: Professor of Chemistry, Royal Veterinary and Agricultural College, Copenhagen, Denmark.....	152
DE BROGLIE, MAURICE, Membre de l'Académie des Sciences de Paris; Directeur du Laboratoire de Physique des Rayons X, Paris, France.....	2
BROWN, F. C., A.B., A.M., Ph.D.: Director, Museums of the Peaceful Arts, New York City.....	141
CADY, WALTER GUYTON, Ph.D.: Professor of Physics, Wesleyan University, Middletown, Connecticut.....	207
CAMPBELL, LESLIE LYLE, Ph.D.: Professor of Physics, Simmons College, Boston, Massachusetts.....	414
CASWELL, A. E., Ph.D.: Professor of Physics, University of Oregon, Eugene, Oregon.....	213
CAU, MARCEL, Agrégé des Sciences Physiques, Docteur ès Sciences: Professeur à l'Université, Constantinople, Turkey.....	425, 435
CHILD, CLEMENT D., Ph.D.: Professor of Physics, Colgate University, Hamilton, New York.....	51
CONANT, JAMES BRYANT, Ph.D.: Professor of Chemistry, Harvard University, Cambridge, Massachusetts.....	333
COTTON, AIMÉ, Docteur ès Sciences: Professeur de Physique à la Sorbonne, Paris, France....	425, 435
CURTIS, HARVEY L., Ph.D.: Principal Physicist, National Bureau of Standards, Washington, D. C.....	74
DAVIS, BERGEN, Ph.D.: Professor of Physics, Columbia University, New York City.....	7
DEFANDORF, F. M., Ph.D.: Associate Physicist, National Bureau of Standards, Washington, D. C.....	74
DRYSDALE, CHARLES VICKERY, O.B.E., D.Sc., M.I.E.E., F.R.S.E.: Superintendent, Admiralty Research Laboratory, Teddington, Middlesex, England.....	156
DUSHMAN, SAUL, Ph.D.: Physicist, General Electric Company, Schenectady, New York.....	53, 56
ECKHARDT, E. A., Ph.D.: Research Department, Gulf Producing and Pipe Line Companies, Pittsburgh, Pennsylvania.....	457
FALK, K. GEORGE, Ph.D.: Chemist, Harriman Research Laboratory, New York University Medical College, New York City.....	309
FARNSWORTH, H. E., Ph.D.: Assistant Professor of Physics, Brown University, Providence, Rhode Island.....	60
FLETCHER, HARVEY, B. S., Ph.D.: Acoustical Research Director, Bell Telephone Laboratories, New York City.....	450
FOËX, GABRIEL: Professeur à l'Université de Strasbourg, Strasbourg, France.....	366
FOLEY, ARTHUR LEE, Ph.D.: Professor of Physics and Head of Physics Department, Indiana University, Bloomington, Indiana..	461
GERKE, ROSCOE H., Ph.D.: Instructor in Physical Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts	332
GRAY, J. A., O.B.E., B.Sc. (Melbourne), D.Sc. (Manchester), F.R.S.C.: Chown Research Professor, Queen's University, Kingston, Ontario, Canada.....	8
HARNED, HERBERT S., Ph.D.: Professor of Chemistry, Yale University, New Haven, Connecticut.....	321
HARRIS, CYRIL C., B.Sc., A.R.C.S., F.C.S.: Research Student in Physical Chemistry, Imperial College of Science and Technology, London, England.....	81
HARTSHORN, L., A.R.C.S., D.I.C., B.Sc.: Senior Assistant, National Physical Laboratory, Teddington, Middlesex, England....	81
HEY, J. A., A.R.C.S., B.Sc., D.I.C.: Junior Scientific Assistant, Admiralty Research Laboratory, Teddington, Middlesex, England	81
HONDA, KÔTARÔ, D.Sc., Honorary member of A.S.S.T.: Professor of Physics, Tôhoku Imperial University and Director of Research Institute for Iron, Steel and other Metals, Sendai, Japan.....	354
HUGHES, ARTHUR LLEWELYN, D.Sc.: Professor of Physics, Washington University, St. Louis, Missouri.....	66, 67
HULL, ALBERT W., Ph.D.: Assistant Director, Research Laboratory, General Electric Company, Schenectady, New York.....	58
ISHIWARA, TORAJIRÔ, D.Sc.: Professor of Metallography, Tôhoku Imperial University, Sendai, Japan.....	354
JONES, T. IORWETH, A.R.C.S., D.I.C., B.Sc.: Assistant, National Physical Laboratory, Teddington, Middlesex, England.....	81
KENDALL, JAMES, M. A., D.Sc., F.R.S.: Professor of Chemistry, University of Edinburgh, Edinburgh, Scotland.....	259
KNOBEL, MAX, Ph.D.: Assistant Professor of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts.....	339
LOEB, LEONARD B., Ph.D.: Associate Professor of Physics, University of California, Berkeley, California.....	110
LUCAS, RENÉ, Docteur ès Sciences Physiques: Chef des Travaux à l'École de Physique et de Chimie, Paris, France.....	425
MACINNES, DUNCAN A., Ph.D.: Associate Member, Rockefeller Institute for Medical Research, New York City.....	312, 338
MACKAY, G. M. J., M.A., S.M.: Research Laboratory, General Electric Company, Schenectady, New York.....	153



# INTRODUCTION

ix

PAGE

MACMAHON, A. M., B.A., M.S., Ph.D.: Head of the Division of Physics and Chemistry, Rosenwald Industrial Museum, Chicago, Illinois.....	141
MILLARD, E. B., Ph.D.: Associate Professor of Physical Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts.....	147
MILLIGAN, ARTHUR G., M.Sc., A.I.C.: Junior Scientific Assistant, Admiralty Research Laboratory, Teddington, Middlesex, England.....	81
MOHLER, F. L., Ph.D.: Physicist, National Bureau of Standards, Washington, D. C.....	69
NICHOLAS, WARREN W., Ph.D.: Physicist, National Bureau of Standards, Washington, D. C.....	23
ONNES, H. KAMERLINGH, Ph.D.: Professor of Physics, University of Leiden, Leiden, Holland.....	124
PARKER, HENRY C., Ph.D.: United States Patent Office, Washington, D. C.....	241
PARINGTON, J. R., M.B.E., D.Sc.: Professor of Chemistry, East London College, University of London, London, England.....	142
ROSS, PERLEY ASON, Ph.D.: Professor of Physics, Stanford University, California.....	49
SABINE, PAUL E., Ph.D.: Department of Acoustics, Riverbank Laboratories, Geneva, Illinois.....	458
SCHLESINGER, H. I., S.B., Ph.D.: Professor of Chemistry and Secretary, Department of Chemistry, University of Chicago, Chicago, Illinois.....	256
SIEGBAHN, MANNE, Ph.D.: Professor of Physics, University of Upsala, Upsala, Sweden.....	23
SMITH, ALPHEUS W., Ph.D.: Professor of Physics, Ohio State University, Columbus, Ohio.....	414
SMYTH, CHARLES P., Ph.D.: Associate Professor and Research Associate, Department of Chemistry, Princeton University, Princeton, New Jersey.....	319
SONÉ, TAKÉ, D.Sc.: Professor of Physics, Rikkyô University, Tokyo, Japan.....	354
SOSMAN, ROBERT B., Ph.D.: Assistant Director, Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C.....	341
STEWART, GEORGE WALTER, Ph.D.: Professor of Physics, University of Iowa, Iowa City, Iowa.....	450
STUHLMAN, JR., OTTO, Ph.D.: Professor of Physics, University of North Carolina, Chapel Hill, North Carolina.....	119
SWANN, WILLIAM FRANCIS GRAY, M.A., D.Sc.: Director of the Bartol Research Foundation of the Franklin Institute, Philadelphia, Pennsylvania.....	442, 445
THIBAUD, JEAN, Docteur ès Sciences, Ingénieur E.S.E.: Sous-Directeur du Laboratoire de Physique des Rayons X.....	2
THOMPSON, MAURICE DEKAY, Ph.D.: Associate Professor of Electrochemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts.....	312
TUYN, W., Ph.D.: Assistant, Physical Laboratory, University of Leiden, Leiden, Holland.....	124
WALLEN, JUDITH E., S.B., M.S.: Department of Chemistry, University of Chicago, Chicago, Illinois.....	256
WATSON, FLOYD ROWE, Ph.D.: Professor of Experimental Physics, University of Illinois, Urbana, Illinois.....	453
WEBSTER, DAVID LOCKE, Ph.D.: Executive Head, Department of Physics, Stanford University, California.....	23
WEISS, PIERRE, Membre de l'Institut de France: Directeur de l'Institut de Physique de l'Université de Strasbourg, Strasbourg, France.....	366
WENNER, FRANK, B.S., Ph.D.: Physicist, National Bureau of Standards, Washington, D. C.....	135
WHITEHEAD, JOHN BOSWELL, Ph.D.: Professor of Electrical Engineering, Johns Hopkins University, Baltimore, Maryland.....	107
WILLIAMS, SAMUEL R., Ph.D.: Professor of Physics, Amherst College, Amherst, Massachusetts.....	439
WILSON, HAROLD A., M.A., D.Sc., F.R.S.: Professor of Physics, Rice Institute, Houston, Texas.....	156
YAMADA, MITUO, D.Sc.: Professor of Physics, Tôhoku Imperial University, Sendai, Japan.....	354



## CONTENTS

	PAGE
X-ray data.....	1
Electronics and gas conduction.....	51
Dielectric properties.....	73
Electrical conductivity and resistivity.....	109
Pyro- and Piezo-electricity.....	207
Thermoelectricity.....	213
Transference numbers of electrolytes in aqueous solution.....	309
Electrolytic electromotive force.....	312
Electrical and optical properties of $\text{SiO}_2$ .....	341
Magnetism.....	345
Atmospheric electricity.....	442
Terrestrial magnetism.....	445
Acoustics.....	450

## MATIERES

	PAGE
Rayons X.....	1
Électronique et conductibilité dans les gaz.....	51
Propriétés diélectriques.....	73
Conductivité et résistivité électriques.....	109
Pyro- et piézo-électricité.....	207
Thermoélectricité.....	213
Nombres de transport des électrolytes en solution aqueuse.....	309
Force électromotrice électrolytique.....	312
Propriétés électriques et optiques de $\text{SiO}_2$ .....	341
Magnétisme.....	345
Électricité atmosphérique.....	442
Magnétisme terrestre.....	445
Acoustique.....	450

## INHALTSVERZEICHNIS

	PAGE
Röntgenstrahlen.....	1
Elektronik und Gas-Leitfähigkeit.....	51
Dielektrische Eigenschaften.....	73
Elektrische Leitfähigkeit und Widerstand.....	109
Pyro- und Piezo-Elektrizität.....	207
Thermoelektrizität.....	213
Überführungs-Zahlen von Elektrolyten in wässriger Lösung.....	309
Elektrolytisches Potential.....	312
Elektrische und optische Eigenschaften von $\text{SiO}_2$ .....	341
Magnetismus.....	345
Atmosphärische Electricität.....	442
Erdmagnetismus.....	445
Akustik.....	450

## INDICE

	PAGE
Raggi X.....	1
Elettronica e conduzione nei gas.....	51
Proprietà dielettriche.....	73
Conducibilità e resistività elettrica.....	109
Piro- e piezo-elettricità.....	207
Termoelettricità.....	213
Numeri di trasporto di elettroliti in soluzione acquosa.....	309
Forza elettromotrice elettrolitica.....	312
Proprietà elettriche ed ottiche della $\text{SiO}_2$ .....	341
Magnetismo.....	345
Elettricità atmosferica.....	442
Magnetismo terrestre.....	445
Acustica.....	450



# INTERNATIONAL CRITICAL TABLES

## X-RAY DATA

COMPLETE INDEX	INDEX COMPLET	GESAMT INDEX VERZEICHNIS	INDICE COMPLETO	PAGE
<i>J</i> -Phenomenon in X-rays.	Phénomène <i>J</i> dans les rayons X.	<i>J</i> -Phänomen bei den Röntgenstrahlen.	Fenomeno <i>J</i> nei raggi X...	1
Polarization of X-rays.	Polarisation des rayons X.	Polarisation von Röntgenstrahlen.	Polarizzazione dei raggi X...	2
Electronic radiation excited by X-rays.	Radiation électronique excitée par les rayons X.	Elektronenstrahlung durch Röntgenstrahlen.	Radiazione elettronica eccitata dai raggi X.....	2
Crystal gratings for X-rays.	Réseaux cristallins pour rayons X.	Kristallgitter für Röntgenstrahlen.	Reticoli cristallini per raggi X.....	7
Absorption and scattering of X-rays.	Absorption et dispersion des rayons X.	Absorption und Streuung von Röntgenstrahlen.	Assorbimento e deviazione dei raggi X.....	8
Emission of X-rays, wavelengths and data on absorption limits.	Emission des rayons X, longueurs d'ondes et données sur les limites d'absorption.	Emission von Röntgenstrahlen, Wellenlängen und Daten über Absorptionsgrenzen.	Emissione di raggi X, lunghezze d'onda e dati sui limiti di assorbimento....	23
Reflection and refraction of X-rays.	Réflexion et réfraction des rayons X.	Reflexion und Brechung von Röntgenstrahlen.	Riflessione e rifrazione dei raggi X.....	49

## *J*-PHENOMENON IN X-RAYS

C. G. BARKLA

As the wave-length ( $\lambda$ ) of the homogeneous (unifrequent) beam of X-rays incident upon a thin sheet of absorbing substance is varied, the absorption by the sheet varies discontinuously at certain values of  $\lambda$ . These absorption edges (or occasionally lines) are sharply defined, and correspond to the frequency required to excite the characteristic radiation (*K*, *L*, *M*, etc.) of the absorber.

When the incident beam is heterogeneous (multifrequent) and its "effective"  $\lambda$  is varied, similar sharp discontinuities in the absorption may occur. The "effective"  $\lambda$  is here defined as the  $\lambda$  of that unifrequent radiation for which the ionization produced in a short air-electroscope is reduced to one-half its value by such a thickness of Al as will produce the same reduction in the ionization of the incident multifrequent beam. It may be specified either in Ångström units, or by the "effective" mass-absorption-coefficient  $(\mu/\rho)$  for the incident beam, as determined by the equation  $e^{-\mu x} = 0.5$ , where  $x$  is the thickness of Al required to reduce the ionization to 0.5 its value;  $\rho$  = density of Al. It must be emphasized that a discontinuity is not associated with either the minimum  $\lambda$  or the  $\lambda$  of maximum intensity of the incident beam, but with some kind of average for the whole beam—possibly analogous to temperature. Also neither the "effective"  $(\mu/\rho)_{Al}$ , nor "effective"  $\lambda$ , is an absolute constant in a given substance; it varies somewhat with other factors for the radiation, which are not yet measurable. The critical "effective"  $(\mu/\rho)_{Al}$  and "effective"  $\lambda$  are thus approximate only. They are only tentative and cannot precisely express the complex quantity involved.

What appear to be distinct series ( $J_1, J_2, \dots$ ) of discontinuities have been observed. Later work has shown that under certain conditions, intermediate discontinuities occur (4). It is possible that a true measure of the fundamental factor involved

will show the critical values for one series to be identical in various substances.

Only tentatively then is the following table given.

### *J*-ABSORPTION EDGES (1, 2, 3, 4)

$(\mu/\rho)_{0.5}$  = "effective" mass absorption coefficient in Al for the multifrequent radiation corresponding to the edge;  $\lambda_e$  = wave-length of unifrequent radiation for which mass absorption coefficient of Al =  $(\mu/\rho)_{0.5}$ . "Effective" coefficient is computed from thickness required to reduce ionization by 50%. Unit of  $(\mu/\rho)_{0.5}$  = 1 cm<sup>2</sup>/g; of  $\lambda$  = 1 Ångström.

Absorber	$(\mu/\rho)_{0.5}$				$\lambda_e$			
	$J_1$	$J_2$	$J_3$	$J_{4,5}^*$	$J_1$	$J_2$	$J_3$	$J_{4,5}^*$
C6.....			1.05				0.39	
N7.....		2.5				0.55		
O8.....	>4	2.2	0.83	0.47	>0.66	0.5	0.355	0.28
Al13.....	3.8	1.9	0.7	0.34	0.63	0.49	0.335	0.23
Si14.....		1.85				0.493		
S16.....		1.7				0.48		
Cu29.....	3.5	1.46	0.6		0.61	0.45	0.315	
Ag47.....	2.0	1.4			0.5	0.45		
Pt78.....			0.57				0.305	
Au79.....			0.54				0.30	

\*  $J_4, J_5$ , or  $J_4$  and  $J_5$ .

### LITERATURE

(For a key to the periodicals see end of volume)

- (1) Barkla, *J*, 49: 1033; 25. (2) Barkla and Khashtgir, *J*, 49: 251; 25. 50: 1115; 25. (3) Barkla and Mackenzie, *J*, 1: 542; 26. (4) Barkla and Watson, *J*, 2: 1122; 26.



## POLARIZATION OF X-RAYS

C. G. BARKLA

The polarization of primary X-rays was discovered by Barkla in 1904 (1, 2), and in 1906 (3) he found that certain scattered X-rays are almost completely polarized: the ionization method of intensity measurement was used. By photographic methods it has been shown that heterogeneous primary radiation from a carbon target (9), and heterogeneous scattered radiation (8) are polarized, that the homogeneous characteristic radiation after reflection in a direction at 90° to the incident radiation is fairly completely polarized (11), and that characteristic radiation excited by homogeneous radiation is unpolarized (11). In order to determine the amount of polarization, the beam is intercepted by a suitable scattering substance, and the variation in the intensity of the rays that are scattered in directions perpendicular to the incident beam is determined. With a variation of 360° in the direction of scattering, this intensity passes through 2 maxima and 2 minima; the difference in azimuth from a maximum ( $M$ ) to a minimum ( $m$ ) is 90°. If the incident beam is compounded of unpolarized radiation of intensity  $R$ , and of plane polarized radiation of intensity  $P$ , then  $M/m = (P + 0.5R)/(0.5R)$ . Hence, fraction ( $p$ ) which is plane polarized is  $P/(P + R) = (M - m)/(M + m)$  and the relative component variation ( $v$ ) is  $(M - m)/M = P/(P + 0.5R)$ .

## DEGREE OF POLARIZATION OF X-RAYS

$P[R]$  = intensity of plane polarized [unpolarized] constituent;  $p = P/(P + R)$ ;  $v = P/(P + 0.5R)$ .  $H[S]$  indicates that incident radiation is hard [soft]. Except where the contrary is indicated, the rays are heterogeneous. Unit of  $v$  and of  $p = 1\%$ .

Rays	Source	$v$		$p$		Lit.
		$H$	$S$	$H$	$S$	
Primary.....	Gas tube*	6	20	3	11	(2, 4)
Primary.....	Gas tube	4	28	2	16	(6)
Primary.....	Gas tube	7	21	4	12	(12)
Primary.....	Gas tube		43†		27†	(12)
Primary.....	Coolidge tube	8	23	4	13	(10)
Primary.....	Coolidge tube	16.5‡	2§	9‡	1§	(10)
Scattered  .....	Carbon	70 + $x$		54 + $y$		(3)
Scattered  .....	$\lambda = 0.25 \text{ \AA}$	95 + $x'$		90 + $y'$		(7)
Characteristic...		0		0		(3, 4)

\* The constituents of higher frequency are the more completely polarized.  
† From Ni target.

‡  $\lambda = 0.3 \text{ \AA}$ .

§  $\lambda = 1 \text{ \AA}$ .

|| Data refer to rays scattered in a direction perpendicular to primary radiation. The true polarization is greater than that actually measured; correction factors  $x$  and  $y$  are necessary owing to obliquity of rays in beams of finite cross-section. Hence polarization of scattered rays in stated direction is approximately complete; i.e., 100%.

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Barkla, 58, 69: 463; 04. (2) Barkla, 62, 204: 467; 05. (3) Barkla, 5, 77: 247; 06. (4) Barkla, 3, 15: 288; 08. (5) Barkla and Sadler, 3, 16: 550; 08. (6) Bassler, 8, 23: 808; 09. (7) Compton and Hagenow, 2, 18: 97; 21. (8) Haga, 8, 23: 439; 07. (9) Herweg, 8, 29: 398; 09. (10) Kirkpatrick, 2, 22: 226; 23. (11) Mark and Sillard, 90, 35: 743; 26. (12) Vegard, 5, 83: 379; 10.

## ELECTRONIC RADIATION EXCITED BY X-RAYS

MAURICE DE BROGLIE AND JEAN THIBAUD

For unexplained symbols, see Vol. I, p.16

## CONTENTS

## MATIÈRES

## INHALTSVERZEICHNIS

## INDICE

## PAGES

Velocity of emitted electrons.

Vitesse des électrons émis.

Geschwindigkeit der emittierten Elektronen.

Velocità degli elettroni emessi.

High velocity electrons.

Électrons à grande vitesse.

Elektronen hoher Geschwindigkeit.

Elettroni ad alta velocità.....

3

Low velocity electrons.

Électrons à petite vitesse.

Langsame Elektronen.

Elettroni a bassa velocità.....

5

Number of electrons emitted.

Nombre d'électrons émis.

Zahl der ausgesendeten Elektronen.

Numero di elettroni emessi.

Variation with emitting substance.

Variation avec la substance émettrice.

Veränderung mit emittierendem Stoff.

Variazione con la sostanza emittente.....

5

Variation with exciting radiation.

Variation avec la radiation excitatrice.

Veränderung mit einwirkender Strahlung.

Variazione con la radiazione eccitante.....

5

Direction of emission.

Direction de l'émission.

Richtung der Emission.

Direzioe dell'emissione.

Solids.

Solides.

Feste Stoffe.

Solidi.....

5

Gases.

Gaz.

Gase.

Gas.

Long range electrons.

Électrons à longue portée.

Elektronen grosser Reichweite.

Elettroni a lungo percorso.....

5

Short range electrons.

Électrons à courte portée.

Elektronen kurzer Reichweite.

Elettroni a corto percorso.....

6

Conductivity of solids and liquids exposed to X-rays.

Conductibilité des solides et liquides exposés aux rayons X.

Leitfähigkeit fester und flüssiger Stoffe unter dem Einfluss von Röntgenstrahlen.

Conducibilità di solidi e liquidi esposti ai raggi X.....

6



Perrin (53) and, later, Curie and Sagnac (27) observed that all kinds of matter emit electrons (28) when irradiated by X-rays. There are two distinct classes of these electrons: Those of one class have a high velocity when emitted and are often called  $\beta$ -rays, and those of the other have a much lower velocity and are often called  $\delta$ -rays. The latter are much the more numerous (65); 85 % of the electrons emitted by gold leaf irradiated by X-rays from a Coolidge tube with a tungsten target have velocities lower than that corresponding to 2 volt.

Wilson (75) and Auger (3, 4) have shown by the fog method that very often a single atom will emit a group of several electrons. In such cases, the X-ray quantum causes initially the ejection of an electron from (e.g.) the  $K$ -level. An  $L$ -electron replaces it and there results an emission of a  $K\alpha$ -ray; this detaches an electron from the  $L$ -level of the same atom. Two  $L$ -rays are thus produced and, in their turn, ionize the more exterior levels. The initial quantum releases 4 photoelectrons. Thus it may be that the energy is not emitted as electromagnetic radiation but within the atom is transformed to the electronic form.

### VELOCITY OF THE EMITTED ELECTRONS

**High Velocity Electrons.**—Among the electrons emitted with high velocity are electrons of all velocities, within a certain range, forming a "continuous spectrum" which corresponds, at least partially, to that of the exciting X-rays. There are also groups of electrons having essentially a common velocity which varies discretely from group to group. The common velocity of each of these groups (v. Table 1) has been found (19, 31, 41, 58, 64) to satisfy the generalized Einstein relation (30)  $m_0 c^2 \{ (1 - \beta^2)^{-1/2} - 1 \} = h\nu - w_0$ , where  $\beta = v/c$ ,  $v$  = velocity of the electron when emitted,  $\nu$  = frequency of the exciting X-rays,  $w_0$  = work done by the electron in escaping from the atom. The value of  $w_0$  depends upon the structure of the atom and the energy-level from which the electron is ejected. Values of  $w_0$  may be determined from ionization potentials ( $V_0$ ) (q.v., p. 69) by the relation  $eV_0 = w_0$ , or from critical absorption-limits, or frequency limits of characteristic X-radiation (v. Emission of X-rays, p. 23), by the simple Einstein relation  $w_0 = h\nu_0$ , where  $\nu_0$  = frequency limit. Some authors (6, 7); cf. (9, 12, 35, 50, 61, 71, 72) have observed in the emission from Ag and Sn a few electrons for which  $w_0 = 0$ . For gases,  $w_0$  is in all cases very small, rare gases of high atomic numbers excepted.

If the X-rays are complex, there will be a group velocity corresponding to each wave-length and to each absorption-level of the atom; and superposed upon this emission will be another, arising from the fluorescent (characteristic) X-radiation emitted by the atoms which are ionized by the primary rays. On passing through a magnetic field these groups are spread out into a magnetic spectrum (19).

The Einstein relation, having been established in many cases, may be used for determining, from the observed velocity of the emitted electrons, (1) the energy corresponding to unknown levels (13, 45) and (2) the wave-length of the exciting radiation (31, 69).

Robinson (57) has discovered an interesting relation involving the electronic emission from the various subdivisions of a given level. The greatest number of electrons comes from the subdivision of smallest energy, (e.g.,  $L_{III}$ ), provided that the critical frequency ( $L$ ) of the element is not too much smaller than the frequency of the incident X-rays. But as the critical frequency is successively reduced by passage from element to element (i.e., as it differs more and more from that of the X-rays), the maximum of intensity of the secondary electrons is displaced towards the subdivision of greatest energy ( $L_I$ ).

From observations with gases Whiddington (71) found that when an electron has passed a distance  $x$  through matter its

velocity has been reduced from  $v_0$  to  $v_x$ , such that  $v_0^4 - v_x^4 = ax$ , where  $a$  is a constant characteristic of the matter. If the unit of  $a$  is  $10^{40}$  cm<sup>3</sup>/sec<sup>4</sup>, the value of  $a$  for air is 2, for Al is 732, and for Au is 2540. If  $R$  = range (unit = 1 cm) in air ( $t = 20^\circ\text{C}$ ,  $p = 1$  atm.) of electrons which have a velocity which may be annulled by a potential difference =  $V$  (unit = 1 volt), then (Wilson (74, 75))  $V = 21\,000\sqrt{R}$  if  $0.1 < R < 1.5$ ; this agrees well with Whiddington's expression.

TABLE 1.—ENERGY ( $E$ ) OF ELECTRONS EMITTED BY ELEMENTARY SUBSTANCES UNDER THE ACTION OF X-RAYS

Observed energy:  $E = eV$ ; calculated energy:  $eV' = h\nu - w_0$ ; Rad. = exciting radiation; Lev. = energy-level from which electron is ejected. X-rays are generated in a Coolidge tube with target of the material indicated. Estimated precision and observer: Cu target (56), 0.5 %; Rh target (19), 2 %; Rh target (73), 1.5 %; W target (19), 2 %. Unit of  $V$  and  $V' = 1$  volt.

$V$	Rad.	Lev.	$V'$
Ag; $Z = 47$ ; target = Cu			
4 237	$K\alpha_1$ Cu	$L_1$	
3 152	$K\alpha_1$ Cu	$L_2$	
4 695	$K\alpha_1$ Cu	$L_3$	
7 382	$K\alpha_1$ Cu	$M_{1,2}$	
7 498	$K\alpha_1$ Cu	$M_3$	
7 708	$K\alpha_1$ Cu	$M_4 - M_5$	
8 006	$K\alpha_1$ Cu	$N$	
Ag; $Z = 47$ ; target = W			
17 940	$K\alpha$ Ag	$L$	18 020
20 900	$K\beta$ Ag	$L$	20 860
32 760	$K\alpha$ W	$K$	32 880
40 990	$K\beta$ W	$K$	41 520
55 140	$K\alpha$ W	$L$	54 730
Al; $Z = 13$ ; target = Rh (73)			
18 440	$K\alpha$ Rh	$K$	18 600
20 660	$K\beta$ Rh	$K$	21 110
As; $Z = 33$ ; target = Rh (73)			
9 135	$K\alpha$ As	$L$	9 094
10 330	$K\beta$ As	$L$	10 290
11 110	$K\beta$ As		11 730
18 190	$K\alpha$ Rh	$L$	18 720
20 860	$K\beta$ Rh	$L$	21 230
23 170	$K\beta$ Rh		22 670
Au; $Z = 79$ ; target = Cu			
4 595	$K\alpha_1$ Cu	$M_1$	
4 875	$K\alpha_1$ Cu	$M_2$	
5 291	$K\alpha_1$ Cu	$M_3$	
5 756	$K\alpha_1$ Cu	$M_4$	
5 843	$K\alpha_1$ Cu	$M_5$	
7 296	$K\alpha_1$ Cu	$N_1 - N_3$	
7 508	$K\alpha_1$ Cu		
7 724	$K\alpha_1$ Cu	$N_{4,5}$	
8 006	$K\alpha_1$ Cu	$N_{6,7}, O$	
Ba; $Z = 56$ ; target = Cu			
2 025	$K\alpha_1$ Cu	$L_1$	
2 421	$K\alpha_1$ Cu	$L_2$	
2 801	$K\alpha_1$ Cu	$L_3$	
3 613	$K\alpha_1$ Cu	*	
4 331	$K\alpha_1$ Cu	*	
6 733	$K\alpha_1$ Cu	$M_1$	
6 880	$K\alpha_1$ Cu	$M_2$	
6 960	$K\alpha_1$ Cu	$M_3$	
7 239	$K\alpha_1$ Cu	$M_{4,5}$	
7 464	$K\alpha_1$ Cu	(?) $KO^\dagger$	

\* Fluorescence,  $L - M$ .  $\dagger KO = K$ -radiation of oxygen.



## INTERNATIONAL CRITICAL TABLES

TABLE 1.—(Continued)

V	Rad.	Lev.	V'	V	Rad.	Lev.	V'
Ba; Z = 56; target = Cu.—(Continued)				Mo; Z = 42; target = Rh (73)			
7 584	K $\alpha_1$ Cu	(?)K $\alpha_1$		14 860	K $\alpha$ Mo	L	14 980
7 842	K $\alpha_1$ Cu	N <sub>1</sub> - N <sub>2</sub>		20 210	K $\beta$ Mo	L	17 120
8 036	K $\alpha_1$ Cu	N <sub>4</sub> - O		19 550	K $\beta$ Mo		19 590
Ba; Z = 56; target = W				Mo; Z = 42; target = W			
26 090	K $\alpha$ Ba	L	25 600	14 070	K $\alpha$ Mo	L	14 690
30 290	K $\beta$ Ba	L	30 000	16 630	K $\beta$ Mo	L	16 910
53 500	K $\alpha$ W	L	52 430	38 680	K $\alpha$ W	K	38 350
Bi; Z = 83; target = Cu				Pb; Z = 82; target = Cu			
4 014	K $\alpha_1$ Cu	M <sub>1</sub>		4 179	K $\alpha_1$ Cu	M <sub>1</sub>	
4 339	K $\alpha_1$ Cu	M <sub>2</sub>		4 468	K $\alpha_1$ Cu	M <sub>2</sub>	
4 844	K $\alpha_1$ Cu	M <sub>3</sub>		4 954	K $\alpha_1$ Cu	M <sub>3</sub>	
5 317	K $\alpha_1$ Cu	M <sub>4</sub>		5 442	K $\alpha_1$ Cu	M <sub>4</sub>	
5 435	K $\alpha_1$ Cu	M <sub>5</sub>		5 557	K $\alpha_1$ Cu	M <sub>5</sub>	
7 065	K $\alpha_1$ Cu	N <sub>1</sub>		7 367	K $\alpha_1$ Cu	N <sub>1,2</sub>	
7 204	K $\alpha_1$ Cu	N <sub>2</sub>		7 605	K $\alpha_1$ Cu	N <sub>4,5</sub>	
7 340	K $\alpha_1$ Cu	N <sub>3</sub>		7 919	K $\alpha_1$ Cu	N <sub>6,7</sub> , O	
7 513	K $\alpha_1$ Cu	N <sub>4</sub>		Rh; Z = 45; target = W			
7 579	K $\alpha_1$ Cu	N <sub>5</sub>		16 790	K $\alpha$ Rh	L	16 870
7 911	K $\alpha_1$ Cu	N <sub>6,7</sub> , O		19 420	K $\beta$ Rh	L	19 510
Bi; Z = 83; target = Rh (73)				35 800	K $\alpha$ W	K	35 180
8 518	L $\alpha$ Bi	M	8 395	Sb; Z = 51; target = W			
10 700	L $\beta$ Bi	M	10 700	21 890	K $\alpha$ Sb	L	21 930
12 340	L $\gamma$ Bi	M	13 000	25 270	K $\beta$ Sb	L	25 350
15 140	L $\gamma$ Bi		15 310	28 810	K $\beta$ Sb	M	28 850
19 710	K $\alpha$ Rh	N	19 920	Se; Z = 34; target = Rh (19)			
22 140	K $\beta$ Rh	N	22 430	8 148	K $\alpha_1$ Rh	K	7 777
Cu; Z = 29; target = Cu				9 053	K $\alpha_1$ Se	L	9 547
6 920	K $\alpha_1$ Cu	L <sub>1</sub>		10 290	K $\beta$ Rh	K	10 370
7 086	K $\alpha_1$ Cu	L <sub>2</sub> - L <sub>3</sub>		17 780	K $\beta$ Se	L	10 780
7 943	K $\alpha_1$ Cu	M		20 660	K $\alpha_1$ Rh	L	18 560
Cu; Z = 29; target = Rh (73)					K $\beta$ Rh	L	21 070
7 078	K $\alpha$ Cu	L	7 119	Sn; Z = 50; target = Cu			
7 942	K $\beta$ Cu	L	7 983	3 563	K $\alpha_1$ Cu	L <sub>1</sub>	
8 929	K $\beta$ Cu		8 888	3 861	K $\alpha_1$ Cu	L <sub>2</sub>	
11 110	K $\alpha$ Rh	K	11 230	4 092	K $\alpha_1$ Cu	L <sub>3</sub>	
12 880	K $\beta$ Rh	(?)K	13 740	7 146	K $\alpha_1$ Cu	M <sub>1</sub>	
18 970	K $\alpha$ Rh	L	19 260	7 317	K $\alpha_1$ Cu	M <sub>2,3</sub>	
20 660	K $\beta$ Rh	L	21 770	7 550	K $\alpha_1$ Cu	M <sub>4</sub> - M <sub>5</sub>	
22 720	K $\beta$ Rh		22 670	7 928	K $\alpha_1$ Cu	N	
Cu; Z = 29; target = Rh (19)				Sn; Z = 50; target = W			
11 360	K $\alpha_1$ Rh	K	11 230	20 580	K $\alpha$ Sn	L	20 820
13 660	K $\beta_1$ Rh	K	13 740	23 700	K $\beta$ Sn	L	24 110
19 260	K $\alpha_1$ Rh	L	19 180	29 220	K $\alpha$ W	K	28 810
21 650	K $\beta_1$ Rh	L	21 690	36 640	K $\beta$ W	K	37 410
I; Z = 53; target = Cu				53 170	K $\alpha$ W	L	53 990
2 841	K $\alpha_1$ Cu	L <sub>1</sub>		Sr; Z = 38; target = Cu			
3 200	K $\alpha_1$ Cu	L <sub>2</sub>		5 793	K $\alpha_1$ Cu	L <sub>1</sub>	
3 463	K $\alpha_1$ Cu	L <sub>3</sub>		6 001	K $\alpha_1$ Cu	L <sub>2</sub>	
6 947	K $\alpha_1$ Cu	M <sub>1</sub>		6 055	K $\alpha_1$ Cu	L <sub>3</sub>	
7 130	K $\alpha_1$ Cu	M <sub>2</sub> - M <sub>3</sub>		7 473	K $\alpha_1$ Cu	(?)K $\alpha$ *	
7 399	K $\alpha_1$ Cu	M <sub>4</sub> - M <sub>5</sub>		7 703	K $\alpha_1$ Cu	(?)M	
7 906	K $\alpha_1$ Cu	N, O		8 026	K $\alpha_1$ Cu	(?)N	
I; Z = 53; target = W				Sr; Z = 38; target = Rh (73)			
23 130	K $\alpha$ I	L	22 920	12 020	K $\alpha$ Sr	L	12 180
27 320	K $\beta$ I	L	26 460	13 740	K $\beta$ Sr	L	13 870
54 650	K $\alpha$ W	L	53 080	15 230	K $\beta$ Sr		15 840
Mo; Z = 42; target = Cu				17 530	K $\alpha$ Rh	L	18 190
5 157	K $\alpha_1$ Cu	L <sub>1</sub>		16 950	K $\beta$ Rh	L	20 700
5 411	K $\alpha_1$ Cu	L <sub>2</sub>		22 390	K $\beta$ Rh		22 670
5 509	K $\alpha_1$ Cu	L <sub>3</sub>		Sr; Z = 38; target = W			
7 646	K $\alpha_1$ Cu	(?)M <sub>2</sub>		11 520	K $\alpha$ Sr	L	12 020
7 783	K $\alpha_1$ Cu	(?)M <sub>3</sub>		13 500	K $\beta$ Sr	L	13 790
7 989	K $\alpha_1$ Cu	(?)N					

\* K $\alpha$  = K-radiation of carbon.\* K $\alpha$  = K-radiation of oxygen.



TABLE 1.—(Continued)

V	Rad.	Lev.	V'
W; Z = 74; target = Cu			
5 206	K $\alpha_1$ Cu	M <sub>1</sub>	
5 465	K $\alpha_1$ Cu	M <sub>2</sub>	
5 761	K $\alpha_1$ Cu	M <sub>3</sub>	
6 148	K $\alpha_1$ Cu	M <sub>4</sub>	
6 226	K $\alpha_1$ Cu	M <sub>5</sub>	
7 605	K $\alpha_1$ Cu	N <sub>1</sub> - N <sub>2</sub>	
7 798	K $\alpha_1$ Cu	N <sub>4</sub> - N <sub>5</sub>	
8 037	K $\alpha_1$ Cu	N <sub>6</sub> - N <sub>7</sub> - O	
W; Z = 74; target = Rh (73)			
6 749	L $\alpha$ W	M	6 666
8 353	L $\beta$ W	M	8 312
9 917	L $\gamma$ W	M	9 958
11 400	L $\gamma$ W		11 600
18 310	K $\alpha$ Rh	M	18 520
20 330	K $\alpha$ Rh		20 160
22 390	K $\beta$ Rh		22 670
Yb; Z = 70; target = W			
41 640	K $\alpha$ Yb	L	42 840
48 560	K $\beta$ Yb	L	49 870
Zn; Z = 30; target = Rh (73)			
7 777	K $\alpha$ Zn	L	7 613
8 847	K $\beta$ Zn <sup>1</sup>	L	8 559
9 629	K $\beta$ Zn		9 547
10 700	K $\alpha$ Rh	K	10 990
13 090	K $\beta$ Rh	(?)K	13 500
18 760	K $\alpha$ Rh	L	19 180
Zn; Z = 30; target = W			
7 407	K $\alpha$ Zn	L	7 366
8 395	K $\beta$ Zn	L	8 312

**Low Velocity Electrons.**—The velocity with which the slow electrons are emitted is independent of the nature of the radiator (63). Shearer (63) attributes these electrons to a secondary effect of the rapid electrons and Simons (65, 66) to the recoil of the atoms from which the rapid electrons are ejected; the latter notes a relation between the distribution of the velocities of these electrons (corresponding to  $T = 11\,000^\circ\text{K}$ ) and that of thermions in a hot body. Their origin may be associated with the diffusion of the incident X-rays, as Compton (24) has shown that the weakly bound electrons can be expelled by a quantum of radiation.

#### NUMBER OF ELECTRONS EMITTED

The total number ( $n_e$ ) of electrons emitted per second is intimately related to the absorption of the X-rays by the substance. The law of fluorescent absorption deduced by Bragg and Peirce,  $\tau A/\rho = CZ^4\lambda^3$ , where  $\tau$  = coefficient of fluorescent absorption (coefficient of absorption after correction for scattering),  $\rho$  = density,  $\lambda$  = wave-length,  $A$  = atomic weight,  $C$  = constant of proportionality, and  $Z$  = atomic number of radiator = number of electrons per atom, has also been deduced from thermodynamics and the quantum theory (20) and by means of the principle of correspondence (43). It indicates (21) that the probability of emission of an electron from an atom of atomic number  $Z$  under action of radiation of intensity ( $I$ ) and frequency ( $\nu$ ) is proportional to  $Z^4\nu^{-4}I$ . Jauncey (38) has recently announced the same result in a somewhat different form. Throughout this report  $I$  is defined as proportional to the total number of ions produced, per second and per unit of solid angle, by complete absorption of the radiation in air. The experimental results are discordant, as follows:

**Variation with Emitting Substance.**—The value of  $n_e$  increases with  $Z$  (Laub (44)), is proportional to  $Z^4$  (Moore (49)), is proportional to  $Z$  (Whiddington (73)). Shearer (63) states that for Al,

Fe, Ni, Cu, Ag, Sn, Au, Pb and Bi, the number ( $N_e$ ) of electrons excited in an atom is  $N_e = K(Z - 10)$ , and consequently  $n_e$  is proportional to the number of electrons contained in an atom. Actually, we observe only those which escape from the body and the law of variation of the absorption (of the electrons) with the velocity is uncertain. This may explain the discordances.

For salts and gases,  $n_e$  increases with the molecular weight; for  $\text{CH}_3\text{I}$ , it is 100 times as great as for air.

**Variation with the Radiation.**—For a given  $I$ ,  $n_e$  decreases as penetration increases,  $n_e \propto V^{-1/2}$  (Shearer (63)), where  $V$  = tube voltage. Hoepner (34) found  $n_e$  decreased more rapidly than  $I$ ; Herweg and Mie (33) found  $n_e \propto I$  even when  $I$  was very small. To obtain concordant results, the number of electrons belonging to each group of uniform velocity should be measured individually, and also the number composing the adjacent portion of the continuous spectrum, and these should be correlated with the distribution of  $I$  in the spectrum of the exciting radiation. This has not been done.

#### DIRECTION OF EMISSION

**Solids.**—For solids, the number of electrons emitted in the direction of propagation of the X-rays exceeds that emitted in the opposite direction (10, 18, 25, 42, 47, 54, 62, 68). This dissymmetry is independent of  $Z$  and of the physical state of the radiator (51); from his experiments with Cu, Wilson (74, 75) concludes that it arises from a curvature in the trajectories of the electrons, rather than a dissymmetry in emission.

**Gases.—Long Range Electrons.**—A polarization of the X-rays leads to a marked lateral concentration of the long range emitted electrons, in the direction of the electric vector of the X-rays (22, 74, 75). The emitted electrons are also concentrated longitudinally in a privileged direction making an acute angle with the direction of propagation of the X-rays. In air, Wilson (74, 75) found the privileged direction was  $45^\circ$  to the X-rays, 20% of the electrons were ejected at  $90^\circ$  (result of polarization) and a few had a backward component. Using polarized X-rays, Bubb (22) found  $\frac{1}{2}$  had a forward component,  $\frac{1}{6}$  had a backward component, and  $\frac{1}{3}$  were almost at  $90^\circ$ . In H, Auger (1) found privileged direction at  $80^\circ$  and the number of electrons with a forward component was about twice as great as that of those with a backward one. For halogens, the longitudinal dissymmetry increases in the order I, Br, Cl, F, and possibly decreases as the tube-voltage decreases (16).

Recent experiments (2, 5, 17, 22) by the fog method show that the most probable direction of ejection of a photoelectron is nearly that of the electric vector of the incident wave but there is an additional component in the direction of propagation of the wave. This component increases when either the potential difference applied to the tube or the frequency of the X-rays is increased (4). When the X-rays are polarized there is a very great preponderance in the number of photoelectrons in the plane containing the electric vector of the incident rays (22). Many attempts to account theoretically for this distribution have been made. Those of Bubb (23); cf. (17) and of Auger and Perrin (5) agree qualitatively with the observations, but neither completely agrees quantitatively.

The origin of the path of a swift electron is marked by a cloud of ions due to the simultaneous emission of a slow electron (1). The initial portion of the path of a swift electron is straight, but deviations of the following 3 kinds become more and more frequent as the velocity decreases: (a) A sudden deflection through a large angle, frequently  $180^\circ$ , due to the electron's passing very near an atomic nucleus. (b) A sudden deflection, which may attain  $45^\circ$ , due to a collision in such a manner with another electron that the latter is ejected, generally at  $90^\circ$  to the path of the primary electron, with sufficient velocity to give rise to a bifurcated or "branch



track" of ions. (c) A progressively curved path due to an accumulation of small deflections of type (b) or, according to some authors, to a gyroscopic action of the electron. The end of the path is marked by a small cloud of ions. Wilson (74, 75) thinks he has shown that, when a tertiary path is grafted upon the main trajectory the two emissions, at the point where the deflection occurs, occur at appreciably different times (0.001 sec). (This conclusion is similar to Bearden's (8) that the emission of fluorescent X-rays occurs  $10^{-5}$  sec after the arrival of the exciting radiation.) Along the entire path there are groups of one or several pairs of ions, apparently due to short and ramified paths of type (b).

**Short Range Electrons.**—Under action of X-rays of sufficiently high frequency a secondary emission of electrons of very short range ("fish-tracks" of 1 to 2 mm, "sphere-tracks" of a few tenths of a mm), which form a distinct class and do not satisfy the quantum relation, has been observed (15, 74, 75) in air, H and He. They are ejected nearly in the direction of propagation of the X-rays. At a tube voltage of 20 kv, there are no fish-tracks in air, and sphere-tracks are rare, but as the voltage increases both increase rapidly, sphere-tracks become fish-tracks and these increase in range (67), and presently short range electrons are more numerous than long range ones. The origin of these electrons is explained by the quantum theory of diffusion of radiation as developed by Compton and Debye; see also (24, 39).

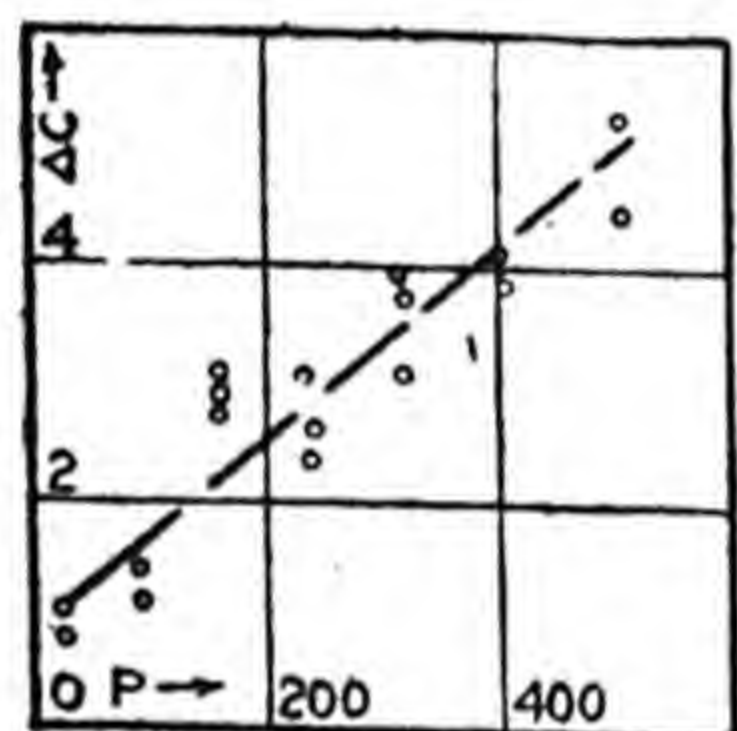


FIG. 1.

FIG. 1.—Effect of pressure ( $P$ ) upon increase ( $\Delta C$ ) in conductance of a crystal of Se when irradiated by X-rays (48).

Unit of  $\Delta C = 10^{-8} \text{ ohm}^{-1}$ , of  $P = 1 \text{ g on area of } 0.064 \text{ mm}^2$ .

FIG. 2.—Progressive increase ( $\Delta C$ ) in conductance of a crystal of Se during irradiation by X-rays, and its recovery after cessation of irradiation (48).

Pressure = 320 g on area of  $0.064 \text{ mm}^2$ ; initial conductance =  $48 \times 10^{-8} \text{ ohm}^{-1}$ . Unit of  $\Delta C = 10^{-8} \text{ ohm}^{-1}$ , of time ( $t$ ) = 1 minute.  $A$  = change during irradiation,  $A'$  = recovery;  $B$  and  $B'$  are similar to  $A$  and  $A'$  but apply to the crystal after it had been fatigued by exposure to  $\gamma$ -rays and had a conductance of  $46 \times 10^{-8} \text{ ohm}^{-1}$ .

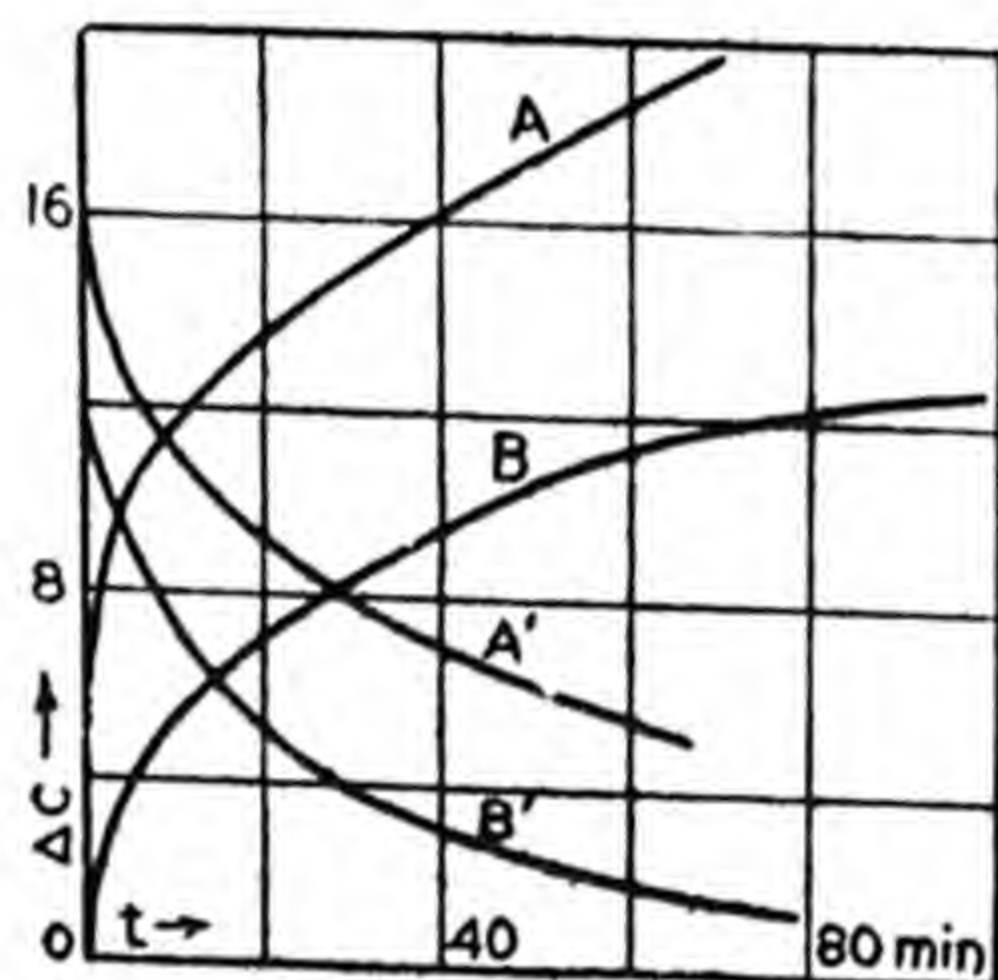


FIG. 2.

## CONDUCTIVITY OF SOLIDS AND LIQUIDS EXPOSED TO X-RAYS

On exposure to X-rays, the conductivity of solids and liquids, especially of dielectrics, is temporarily increased (11, 14, 26, 36, 40, 70). The increases in the conduction of a crystal of Se after an exposure of 1 min to light ( $\lambda = 7000 \text{ \AA}$ ), to X-rays ( $\lambda = 1.5 \text{ \AA}$ ) and to  $\gamma$ -rays ( $\lambda = 0.03$  to  $0.4 \text{ \AA}$ ) were 33.2, 58.5, and  $108.9 \text{ ohm}^{-1}$  per joule absorbed, respectively (48, 52). For variation with time and pressure, see Figs. 1 and 2. The conductivity of a plate of NaCl increases during exposure to X-rays, and gradually decreases after the X-rays are withdrawn; the exposure "activates" the plate for future action of ordinary light (59). The conductivity of S increases considerably under action of X-rays; the increase is proportional to intensity of the radiation and varies with the nature of the rays in same manner as the ionization of air; in the range of potential difference investigated (69 to 204 volt) the

conduction satisfies Ohm's law; the conductivity conferred by irradiation is 3 times as great for monoclinic as for rhombohedral sulfur (32). The conductivity of crystals of calcite ( $\text{CaCO}_3$ ), of fluorite ( $\text{CaF}_2$ ), and of feldspar is increased by radiation (46), and the property of luminescence, previously reduced by heating, is restored. The apparent charges of a permanently polarized dielectric are temporarily destroyed by exposure to X-rays (29).

Under action of X-rays, insulating liquids acquire a conductivity which satisfies Ohm's law if the potential gradient does not exceed about 700 volt per cm; the value of this conductivity for a certain unstated radiation is given in Table 2. There is no appreciable dissociation of the molecules, cf. (37). Recently, del Regno (55) has studied the variation in the electrical resistance of a selenium cell subjected to the radiations from mesothorium, and Ross (60) has studied the increase in the conductivity of solid dielectrics (sulfur, paraffin, ebonite, amber) subjected to X-rays. For action of  $\gamma$ -rays, see (36).

TABLE 2.—CONDUCTIVITY ( $C$ ) OF INSULATING LIQUIDS WHEN EXPOSED TO X-RAYS (26, 36)

Quality and intensity of X-rays are not stated, unit of  $C = 10^{-4} \text{ ohm}^{-1} \text{ cm}^{-1}$

Formula	Name	$C$
$\text{CCl}_4$	Carbon tetrachloride.....	8
$\text{CS}_2$	Carbon disulfide.....	20
$\text{C}_6\text{H}_{10}$	Amylene.....	14
$\text{C}_6\text{H}_6$	Benzene.....	4
	Liquid air.....	1.3
	Petroleum ether.....	15
	Vaseline oil.....	1.6

## LITERATURE

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## CRYSTAL GRATINGS FOR X-RAY SPECTROSCOPY

BERGEN DAVIS

The wave-length of X-rays is usually determined either by means of the ionization spectrometer or by a photographic method. With suitable crystals, the former is probably the more accurate, but it requires uniform reflecting planes sufficiently large to reflect a considerable amount of energy. The photographic method may be used with small irregular crystals and is particularly useful with powdered crystals.

**Grating Constant.**—The grating constant of a crystal is usually measured in terms of that of either calcite ( $\text{CaCO}_3$ ) or rock salt ( $\text{NaCl}$ ), the constant of the standard being calculated from crystal data and other physical constants. Even the best specimens of rock salt are imperfect crystals, the reflecting planes being not uniformly parallel planes throughout any considerable volume of the crystal; also the rocking curves obtained by means of the double X-ray spectrometer are wide (11.1), indicating that the crystal elements are quite imperfect. Calcite (Iceland spar) is much more nearly perfect; for it, the rocking curves are very smooth and narrow (less than  $\frac{1}{60}$  of the width of the rock salt curves).

On account of the perfection of its crystal structure, it is recommended that calcite (Iceland spar) be selected as the primary standard in all measurements of the wave-lengths of X-rays; and that the value  $d_{100} = (3.029 \pm 0.001) \times 10^{-8}$  cm (at  $20^\circ\text{C}$ ) be used. This value of  $d_{100}$  for calcite is as probable as any other value yet deduced; it is equivalent (27) to  $d_{100} = 2.814 \times 10^{-8}$  cm (at  $20^\circ\text{C}$ ) for rock salt. A large number of measurements have already been made in terms of one or other of these equivalent values.

If  $a_0$  = length of edge of unit crystal form, the observed grating space for the planes ( $h, k, l$ ) of a face-centered cubic crystal, like rock salt, is  $d_{hkl} = a_0/\sqrt{h^2 + k^2 + l^2}$  if  $h, k$ , and  $l$  are all odd, and in all other cases  $d_{hkl} = 0.5a_0/\sqrt{h^2 + k^2 + l^2}$ . For face-centered rhombohedral crystals  $a_0\sqrt{1 + 2\cos^2\beta - 3\cos^2\beta/\sqrt{(h^2 + k^2 + l^2)\sin^2\beta + 2(hk + hl + kl)(\cos^2\beta - \cos\beta)}}$ , where  $\beta$  = angle between edges of unit rhombohedron, replaces  $a_0/\sqrt{h^2 + k^2 + l^2}$  of the preceding cubic expressions. In cubic crystals  $a_0 = (nV_m)^{1/3}$ , where  $n$  = number of molecules in the elementary crystal unit and  $V_m (= M/\rho N_0)$  is the molecular volume,  $M$  = molecular weight,  $\rho$  = density,  $N_0$  = Avogadro's number = number of molecules per mole. The value of  $n$  depends upon the crystal structure. For both rock salt ( $\text{NaCl}$ ) and calcite ( $\text{CaCO}_3$ ),  $n = 4$ . The main sources of error lie in the determination of  $\rho$  and  $N_0$ .

For calcite,  $2d_{100} = [4V_m/\varphi(\beta)]^{1/2}$ , where  $\varphi(\beta)$  = volume of the calcite rhombohedron which has unit distance between the (100) planes =  $(1 + \cos\beta)^2/(\sin\beta)(1 + 2\cos\beta) = 1.0962$ , as  $\beta = 101^\circ 55'$ . Compton (6) found  $\rho = 2.7116$ , corrected to  $2.7102$  g/cm<sup>3</sup>, at  $20^\circ\text{C}$ , and Compton, Beets, and Defoe (8) also found  $2.7102$  at  $20^\circ\text{C}$ . This value of  $\rho$  together with the I. C. T. values for  $M$  and  $N_0$  (Vol. I, p. 18 and 43) lead to  $d_{100} = (3.029 \pm 0.001) \times 10^{-8}$  cm at  $20^\circ\text{C}$ . Other values for  $\rho$  are  $2.716$  (9) and  $2.715$  (3); the average of these and the preceding two is  $2.713$  which gives  $d_{100} = (3.028 \pm 0.002) \times 10^{-8}$  cm at  $20^\circ\text{C}$ .

Some of the better determinations of  $\rho$  for rock salt are  $2.167$  at  $17^\circ\text{C}$  (24, 25),  $2.15$  (9),  $2.170$  (15),  $2.167$  (22),  $2.174$  (19),  $2.161$  (1) and  $2.1632$  (13). The mean of these ( $2.166$ ) gives  $d_{100} =$

$(2.814 \pm 0.002) \times 10^{-8}$  cm at  $20^\circ\text{C}$ . A more recent determination (14) gives  $d_{100} = 2.814[1 + 0.00004(t - 18)] \times 10^{-8}$  cm at  $t, ^\circ\text{C}$ .

## GRATING SPACES OF SELECTED CRYSTALS

(c) = measured in terms of calcite,  $d_{100} = 3.029$ ; (r) = measured in terms of rock-salt,  $d_{100} = 2.814$ .  $a_0$  = length of edge of the unit crystal form;  $d$  = grating space, temperature =  $20^\circ\text{C}$ . For other data, see (2, 20, 23, 26, 29, 30). Unit of  $a_0$  and of  $d = 1 \text{ \AA} = 10^{-8}$  cm.

Symbol	Crystal	System	Plane	$a_0$	$d$	Lit.
$\text{CaCO}_3$	Calcite	Rhomb.*	100	6.9347	$3.029 \pm 0.001$	(Calc.)
$\text{NaCl}$	Rock salt	Cubic	100	5.628	2.814	(3)
$\text{FeS}_2$	Pyrite	Cubic	100 (2)	5.4056	2.703 (c)	(10, 11)
$\text{KCl}$	Sylvite	Cubic	100	6.272	3.136 (r)	(31)
$\text{KI}$	K iodide	Cubic	100	7.064	3.533 (c)	(5)
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	Gypsum	Monoc.*	010		7.584 (r)	(28)
	Mica	Monoc.*	001		10.1 (r)	(4)
$\text{C}_{12}\text{H}_{22}\text{O}_{11}$	Cane sugar	Monoc.*	100		10.570 (r)	(28)

\* Rhomb. = rhombohedral; Monoc. = monoclinic.

**Refraction.**—If the surface of the crystal is parallel to the reflecting planes in the crystal, if  $n$  is the order of the spectrum, and  $\theta$  is the glancing angle of reflection corresponding to the maximum intensity of radiation of wave-length  $\lambda$ , then  $n\lambda = 2d \sin\theta(1 - \delta \cot^2\theta)$ , where  $1 - \delta$  is the index of refraction of the crystal for radiation of wave-length  $\lambda$ . Measurements of  $\delta$  for calcite (16) and for pyrites (10, 11) show (10, 11) that  $\delta = \frac{e^2}{2\pi m} \times \left[ \frac{n_1}{\nu^2 - \nu_1^2} + \frac{n_2}{\nu^2 - \nu_2^2} + \dots \right]$ , where  $\nu$  = frequency of incident radiation and  $n_1, n_2, \dots$  are the numbers of electrons per unit volume having the critical absorption (resonance) frequencies  $\nu_1, \nu_2, \dots$ . As  $\nu_1, \nu_2, \dots$  are generally small as compared with  $\nu$ , a first approximation is  $\delta = \frac{e^2}{2\pi m} \left[ \frac{n_1 + n_2 + \dots}{\nu^2} \right]$ . For refraction of X-rays, see p. 49, and also (7, 12, 17, 18, 21).

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ABSORPTION AND SCATTERING OF X-RAYS<sup>1</sup>

J. A. GRAY

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Introduction.	Introduction.	Einleitung.	Introduzione.	
Symbols and units.	Symboles et unités.	Symbole und Einheiten.	Simboli e unità.....	8
Restriction.	Restriction.	Restriktion.	Limiti.....	10
Absorption and scattering.	Absorption et dispersion.	Absorption und Streuung.	Assorbimento e disper-	
			sione.....	10
Extinction.	Extinction.	Verlöschung, Extinktion.	Estinzione.....	10
Efficiency of emission of	Efficacité de l'émission d'une	Leistung der Emission cha-	Efficienza dell'emissione	
characteristic radiation.	radiation caractéristique.	rakteristischer Strahlung.	della radiazione carat-	
			teristica.....	10
Definitions.	Définitions.	Definitionen.	Definizioni.....	11
Absorption.	Absorption.	Absorption.	Assorbimento.	
Variation with wave-length	Variation avec la longueur	Änderung mit der Wellen-	Variatione con il variare	
and absorber.	d'onde et la substance	länge und des Absorbens.	della lunghezza d'onda	
	absorbante.		e del mezzo assorbente	12
Coefficients of absorption	Coefficients d'absorption	Absorptionskoeffizient für $\lambda$	Coefficienti di assorbi-	
for $\lambda = 0.586, 0.631$ and	pour $\lambda = 0.586, 0.631$ , et	$= 0.586, 0.631$ und $0.709 \text{ \AA}$ .	mento per $\lambda = 0.586,$	
$0.709 \text{ \AA}$ .	$0.709 \text{ \AA}$ .		$0.631$ e $0.709 \text{ \AA}$ .....	12
Coefficients of absorption	Coefficients d'absorption	Absorptionskoeffizient für	Coefficienti di assorbi-	
for X-rays and $\gamma$ -rays.	pour les rayons X et les	Röntgen- und $\gamma$ -Strahlen.	mento per i raggi X e	
	rayons $\gamma$ .		i raggi $\gamma$ .....	14
Scattering.	Dispersion.	Streuung.	Dispersione.	
Change in wave-length.	Changement de la longueur	Änderung der Wellenlänge.	Cambiamento di lun-	
	d'onde.		ghezza d'onda.....	17
Distribution of scattered	Distribution de la radiation	Verteilung der gestreuten	Distribuzione della radi-	
radiation.	dispersée.	Strahlung.	azione dispersa.....	18
Relations between absorption,	Relations entre l'absorption, la	Beziehungen zwischen Ab-	Relazione tra l'assorbi-	
scattering and electron emis-	dispersion et l'émission élec-	sorption, Streuung und	mento, la dispersione e	
sion.	tronique.	Elektronenemission.	l'emissione di elettroni..	20
Apparent coefficients of absorp-	Coefficients apparents d'absorp-	Scheinbare Absorptionskoeffi-	Coefficienti apparenti di	
tion.	tion.	zienten.	assorbimento.....	20

## INTRODUCTION

**Symbols and Units.**—Unless the contrary is stated, the unit of  $\lambda$  and of  $\delta\lambda$  is  $1 \text{ \AA}$ , and that of each of the other quantities is the appropriate cgs unit.  $c, e, h, m_0$  have their usual significance (Vol. I, p. 16).

- $A$  Atomic weight.  
 $a$  Area perpendicular to direction of propagation of the radiation.  
 $F$  Scattering function.  
 $I$  Intensity of incident radiation;  $I = dP/da$ .  
 $I_\theta$  Power of the radiation scattered, per unit solid angle, at angle  $\theta$ , per unit volume of the scatterer.  
 $I_{\theta\omega}$  Power of the radiation scattered, per unit solid angle, at angle  $\theta$ , per atom of the scatterer;  $I_{\theta\omega} = AI_\theta/N_{\omega\phi}$ .  
 $M$  Molecular weight.  
 $N_0$  Avogadro's constant, molecules per gram-mole.  
 $n_K$  Number of K-electrons in the atom; similarly for  $n_L$ , etc.  
 $P$  Power carried by the radiation.  
 $R_L^K$  Discontinuity in photoelectric absorption at K-limit.  
 $R$  R-electron = recoil electron.  
 $U$  U-electron is an electron that scatters unmodified radiation.  
 $V$  Difference in potential of terminals of X-ray tube.  
 $v$  Volume.  
 $Z$  Atomic number.  
 $\alpha$   $h\nu/m_0c^2 = 0.0243$  if  $\lambda$  is expressed in  $\text{\AA}$ .  
 $\epsilon$  Extinction coefficient.  
 $\eta$   $e^2/m_0^2c^4$ .

<sup>1</sup> Covers data prior to October, 1927.

## INTRODUCTION

**Symboles et unités.**—À moins d'une autre indication, l'unité pour  $\lambda$  et pour  $\delta\lambda$  est  $1 \text{ \AA}$ , et celle pour chaque autre quantité est l'unité cgs appropriée.  $c, e, h, m_0$  ont leur signification habituelle (Vol. I, p. 16).

- $A$  Poids atomique.  
 $a$  Surface perpendiculaire à la direction de propagation de la radiation.  
 $F$  Fonction de dispersion.  
 $I$  Intensité de la radiation incidente;  $I = dP/da$ .  
 $I_\theta$  Pouvoir de la radiation dispersée par unité de l'angle solide, à l'angle  $\theta$ , par unité de volume du corps dispersant.  
 $I_{\theta\omega}$  Pouvoir de la radiation dispersée par unité de l'angle solide, à l'angle  $\theta$ , par atome du corps dispersant;  $I_{\theta\omega} = AI_\theta/N_{\omega\phi}$ .  
 $M$  Poids moléculaire.  
 $N_0$  Constante d'Avogadro, nombre de molécules par Mol. gr.  
 $n_K$  Nombre d'électrons-K dans l'atome; de même pour  $n_L$ , etc.  
 $P$  Puissance portée par la radiation.  
 $R_L^K$  Discontinuité dans l'absorption photoélectrique à la limite-K.  
 $R$  Electron-R = électron de recul.  
 $U$  Electron-U est un électron qui disperse une radiation non modifiée.  
 $V$  Différence de potentiel entre les extrémités d'un tube à rayons X.  
 $v$  Volume.  
 $Z$  Nombre atomique.  
 $\alpha$   $h\nu/m_0c^2 = 0.0243$  si  $\lambda$  est exprimé en  $\text{\AA}$ .  
 $\epsilon$  Coefficient d'extinction.



$\theta$	Angle of scattering as measured from direction of propagation of incident radiation.
$\lambda$	Wave-length.
$\mu$	Coefficient of absorption; $\mu = \tau + \sigma$ .
$\mu'$	Apparent coefficient of absorption, the value found when scattered radiations are not completely eliminated from the transmitted beam.
$\mu_a$	Coefficient of atomic absorption; $\mu_a = \mu A / \rho N_0$ .
$\mu_m$	Coefficient of molecular absorption; $\mu_m = \mu M / \rho N_0$ .
$\mu_e$	Coefficient of electronic absorption; $\mu_e = \mu A / \rho N_0 Z = \mu_a / Z$ .
$\nu$	Frequency of incident ( $\nu'$ = modified) radiation.
$\nu_c$	Critical frequency corresponding to an absorption-limit.
$\rho$	Density.
$\sigma$	Coefficient of scattering; $\sigma = \sigma_s + \sigma_a$ .
$\sigma_a$	Coefficient of true absorption due to scattering.
$\sigma_s$	Coefficient of true scattering.
$\sigma_a, \sigma_e, \sigma_{aa}, \sigma_{ae}, \sigma_{sa}, \sigma_{se}$	(See corresponding notation for $\mu$ ).
$\tau$	Coefficient of photoelectric absorption.
$\tau_a, \tau_m, \tau_e$	(See corresponding notation for $\mu$ ).
$\phi$	Efficiency of emission of characteristic radiation; $\phi$ = ratio of number of atoms emitting the radiation to the number from which corresponding photoelectrons are ejected.
$\varphi$	Angle of ejection of recoil electron, as measured from direction of propagation of incident radiation.
$\psi$	An angle.
$\omega$	Solid angle.

## EINLEITUNG

**Symbole und Einheiten.**—Wenn nicht anders bemerkt, ist die Einheit von  $\lambda$  und  $\delta\lambda$  1 Å, und die für jede der anderen Größen die dazugehörige im cgse System.  $c, e, h, m_0$  haben deren gewöhnliche Bedeutung (Bd. I, S. 16).

$A$	Atomgewicht.
$a$	Fläche senkrecht zur Fortpflanzungsrichtung der Strahlung.
$F$	Streuungsfunktion.
$I$	Intensität der einfallenden Strahlung; $I = dP/da$ .
$I_{\theta}$	Kraft der gestreuten Strahlung, pro Einheit des festen Winkel, beim Winkel $\theta$ , pro Volumeinheit des streuenden Stoffes.
$I_{\theta a}$	Kraft der gestreuten Strahlung, pro Einheit des festen Winkel, beim Winkel $\theta$ , pro Atom des streuenden Stoffes; $I_{\theta a} = AI_{\theta}/N_0\rho$ .
$M$	Molekulargewicht.
$N_0$	Avogadro-Konstante, Moleküle pro Gramm-Mol.
$n_K$	Zahl der K-Elektronen pro Atom; in gleicher Weise für $n_L$ , u. s. w.
$P$	Kraft der Strahlung.
$R_L^K$	Diskontinuität der photoelektrischen Absorption an der K-Grenze.
$R$	R-Elektron = Rückstoss-Elektron.
$U$	U-Elektronen sind solche, welche unmodifizierte Strahlung streuen.
$V$	Grenzpotentialdifferenz von Röntgen-Röhren.
$\nu$	Volumen.
$Z$	Atomnummer.
$\alpha$	$h\nu/m_0c^2 = 0,0243$ wenn $\lambda$ in Å ausgedrückt.
$\epsilon$	Extinktionskoeffizient.
$\eta$	$e^4/m_0^2c^4$ .
$\theta$	Streuungswinkel gemessen an der Richtung der fortschreitenden einfallenden Strahlung.
$\lambda$	Wellenlänge.

$\eta$	$e^4/m_0^2c^4$ .
$\theta$	Angle of dispersion tel qu'il est mesuré à partir de la direction de propagation de la radiation incidente.
$\lambda$	Longueur d'onde.
$\mu$	Coefficient d'absorption; $\mu = \tau + \sigma$ .
$\mu'$	Coefficient apparent d'absorption; c'est la valeur trouvée lorsque les radiations dispersées ne sont pas complètement éliminées du rayon transmis.
$\mu_a$	Coefficient d'absorption atomique; $\mu_a = \mu A / \rho N_0$ .
$\mu_m$	Coefficient d'absorption moléculaire; $\mu_m = \mu M / \rho N_0$ .
$\mu_e$	Coefficient d'absorption électronique; $\mu_e = \mu A / \rho N_0 Z = \mu_a / Z$ .
$\nu$	Fréquence de la radiation incidente ( $\nu'$ = modifiée).
$\nu_c$	Fréquence critique correspondant à une limite d'absorption.
$\rho$	Densité.
$\sigma$	Coefficient de dispersion; $\sigma = \sigma_s + \sigma_a$ .
$\sigma_a$	Coefficient d'absorption vraie due à la dispersion.
$\sigma_s$	Coefficient de dispersion vraie.
$\sigma_a, \sigma_e, \sigma_{aa}, \sigma_{ae}, \sigma_{sa}, \sigma_{se}$	(Voir la notation correspondante pour $\mu$ ).
$\tau$	Coefficient d'absorption photoélectrique.
$\tau_a, \tau_m, \tau_e$	(Voir la notation correspondante pour $\mu$ ).
$\phi$	Efficacité de l'émission de la radiation caractéristique; $\phi$ = rapport du nombre d'atomes émettant la radiation, au nombre de ceux à partir desquels les photoélectrons correspondants sont expulsés.
$\varphi$	Angle d'éjection de l'électron de recul, tel qu'il est mesuré à partir de la direction de propagation de la radiation incidente.
$\psi$	Un angle.
$\omega$	Angle solide.

## INTRODUZIONE

**Simboli e unità.**—A meno che non venga altrimenti indicato le unità di  $\lambda$  e di  $\delta\lambda$  è 1 Å e quello di ogni altra quantità sono le unità appropriate del sistema cgse.  $c, e, h, m_0$  hanno il loro consueto significato (Vol. I, p. 16).

$A$	Peso atomico.
$a$	Area perpendicolare alla direzione di propagazione della radiazione.
$F$	Funzione di dispersione.
$I$	Intensità della radiazione incidente; $I = dP/da$ .
$I_{\theta}$	Potenza della radiazione dispersa, per unità di angolo solido, a un angolo $\theta$ , per unità di volume del mezzo dispersore.
$I_{\theta a}$	Potenza della radiazione dispersa, per unità di angolo solido, a un angolo $\theta$ , per atomo del mezzo dispersore; $I_{\theta a} = AI_{\theta}/N_0\rho$ .
$M$	Peso molecolare.
$N_0$	Costante di Avogadro, molecole per grammomolecola.
$n_K$	Numero di elettroni K nell'atomo; similmente per $n_L$ , ecc.
$P$	Potenza portata dalla radiazione.
$R_L^K$	Discontinuità nell'assorbimento fotoelettrico al limite K.
$R$	R-elettrone = elettrone di rimbalzo.
$U$	U-elettrone è un elettrone che disperde la radiazione immoificata.
$V$	Differenza di potenziale ai termini del tubo a raggi X.
$\nu$	Volume.
$Z$	Numero atomico.
$\alpha$	$h\nu/m_0c^2 = 0,0243$ se $\lambda$ è espressa in Å.
$\epsilon$	Coefficiente di estinzione.
$\eta$	$e^4/m_0^2c^4$ .
$\theta$	Angolo di dispersione come viene misurato dalla direzione di propagazione della radiazione incidente.
$\lambda$	Lunghezza d'onda.
$\mu$	Coefficiente di assorbimento; $\mu = \tau + \sigma$ .
$\mu'$	Coefficiente apparente di assorbimento; il valore trovato



- $\mu$  Absorptionskoeffizient;  $\mu = \tau + \sigma$ .
- $\mu'$  Scheinbarer Absorptionskoeffizient, der Wert, der sich ergibt, wenn die gestreute Strahlung nicht vollständig frei vom durchdringenden Strahl ist.
- $\mu_a$  Koeffizient der Atom-Absorption;  $\mu_a = \mu A / \rho N_0$ .
- $\mu_m$  Koeffizient der Molekularabsorption;  $\mu_m = \mu M / \rho N_0$ .
- $\mu_e$  Koeffizient der Elektronen Absorption;  $\mu_e = \mu A / \rho N_0 Z = \mu_a / Z$ .
- $\nu$  Frequenz der einfallenden Strahlung ( $\nu'$  = modifiziert).
- $\nu_c$  Kritische Frequenz entsprechend einer Absorptionsgrenze.
- $\rho$  Dichte.
- $\sigma$  Streukoeffizient;  $\sigma = \sigma_s + \sigma_a$ .
- $\sigma_a$  Koeffizient der wahren Absorption durch Streuung.
- $\sigma_s$  Koeffizient der wahren Streuung.
- $\sigma_a, \sigma_s, \sigma_{aa}, \sigma_{as}, \sigma_{sa}, \sigma_{ss}$  (Siehe die entsprechenden Bemerkungen für  $\mu$ ).
- $\tau$  Koeffizient der photoelektrischen Absorption.
- $\tau_a, \tau_m, \tau_e$  (Siehe die entsprechende Bemerkungen für  $\mu$ ).
- $\phi$  Leistung der Emission charakteristischer Strahlung;  $\phi =$  Verhältnis der Anzahl der Strahlung aussendenden Atome zu der Anzahl von welchen entsprechende photoelektrische Elektronen abgestossen werden.
- $\psi$  Winkel unter welchem Rückstosselektronen abgestossen werden, gemessen von der Richtung des Fortschreitens der einfallenden Strahlung.
- $\psi$  Winkel.
- $\omega$  Fester Winkel.

- quando le radiazioni disperse non sono completamente eliminate dal fascio trasmesso.
- $\mu_a$  Coefficiente di assorbimento atomico;  $\mu_a = \mu A / \rho N_0$ .
- $\mu_m$  Coefficiente di assorbimento molecolare;  $\mu_m = \mu M / \rho N_0$ .
- $\mu_e$  Coefficiente di assorbimento elettronico;  $\mu_e = \mu A / \rho N_0 Z = \mu_a / Z$ .
- $\nu$  Frequenza della radiazione incidente ( $\nu'$  = modificata).
- $\nu_c$  Frequenza critica corrispondente ad un assorbimento limite.
- $\rho$  Densità.
- $\sigma$  Coefficiente di dispersione;  $\sigma = \sigma_s + \sigma_a$ .
- $\sigma_a$  Coefficiente di assorbimento vero dovuto a dispersione.
- $\sigma_s$  Coefficiente di dispersione vero.
- $\sigma_a, \sigma_s, \sigma_{aa}, \sigma_{as}, \sigma_{sa}, \sigma_{ss}$  (Vedi la notazione corrispondente per  $\mu$ ).
- $\tau$  Coefficiente di assorbimento fotoelettrico.
- $\tau_a, \tau_m, \tau_e$  (Vedi la corrispondente notazione per  $\mu$ ).
- $\phi$  Efficienza dell'emissione della radiazione caratteristica;  $\phi =$  rapporto fra il numero di atomi che emettono la radiazione e il numero di quelli dai quali vengono emessi fotoelettroni.
- $\psi$  Angolo di eiezione dell'elettrone di rimbalzo, quale viene misurato dalla direzione di propagazione della radiazione incidente.
- $\psi$  Un angolo.
- $\omega$  Un angolo solido.

**Restriction.**—Unless the opposite is explicitly stated (Tables 11, 12, 13), it is assumed, throughout this report, that in determining absorption coefficients, the measuring instrument is so far from the absorbing material and is so screened that it indicates merely the intensity of the radiant energy which is traveling in the direction of the primary beam. It is the absorption, as so measured, that is considered, and to which the coefficients of absorption refer.

Obviously the amount of radiation reaching a given region within the absorbing material cannot be computed directly from this absorption, for that region receives scattered and characteristic radiations from all the surrounding material, traveling in every direction. This extra radiation may be several times as great as that incident in the direction of the primary beam, and it is only the latter that can be computed directly from the coefficient of absorption. This difference is of much importance in the use of X-rays for therapeutic purposes, and has been studied by many *cf.* (141, 231).

**Absorption and Scattering.**—When a beam of X-rays passes through an atomic system, it may be altered by the action of the non-nuclear electrons. The following three types of action are recognized, though types (b) and (c) are parts of the same general phenomenon.

(a) **Photoelectric Effect.**—An electron is dislodged from its energy-level, and absorbs all the energy  $h\nu$  of the impinging quantum. Such electrons are called photoelectrons, and are emitted with the energy  $h(\nu - \nu_c)$ , where  $\nu_c$  is the frequency characteristic of the level from which they come. They may be described as primary photoelectrons. The vacancy caused by the removal of a photoelectron is soon refilled by an electron from a lower energy-level having a characteristic frequency  $\nu_c'$ . Accompanying this, there may be an emission of characteristic radiation which, on an average, is uniform in all directions, and has a frequency  $(\nu_c - \nu_c')$  and energy  $h(\nu_c - \nu_c')$ . This is the simple photoelectric effect.

From some of the atoms this characteristic radiation is not emitted, but additional electrons, which may be called secondary photoelectrons, are emitted. This is the compound photoelectric

effect. The characteristic radiation may be regarded as being absorbed in the atom and causing the ejection of photoelectrons from other levels, with energies  $h(\nu_c - \nu_c')$ ,  $h(\nu_c' - \nu_c'')$ , etc.

(b) **Scattering without Change of Frequency.**—An electron, though not dislodged from its energy-level, may cause a scattering of the primary radiation. This scattered radiation has the same frequency as the primary, and is called the unmodified scattered radiation. Such electrons may be called *U*-electrons. They scatter the radiation coherently.

(c) **Scattering with Change of Frequency.**—An electron may be dislodged from its energy-level without absorbing more than a fraction,  $(\nu - \nu')/\nu$ , of the energy of the impinging quantum. Such an electron is called a "recoil" (or an *R*-) electron. It leaves the atom with energy  $h(\nu - \nu' - \nu_c)$ , radiation of frequency  $\nu'$ , differing from  $\nu$ , is scattered, and characteristic radiation of frequency  $(\nu_c - \nu_c')$  is emitted as the vacancy is refilled by an electron from the level  $\nu_c'$ . This scattered radiation is known as the modified scattered radiation. It is not scattered coherently.

**Extinction.**—Darwin (123, 124) has shown that when a crystal is set so as to reflect the incident rays, the effective absorption should be greater than the true. This phenomenon is due to what is called extinction and has been observed, *cf.* (20, 58, 60, 63, 220); see Table 5, NaCl. For a perfect crystal, extinction occurs only when the orientation is such as to reflect the incident beam, and arises from the fact that beams which have been twice reflected are parallel to and exactly opposite in phase to the primary beam. This is called primary extinction. An imperfect crystal may be regarded as a mosaic of small perfect crystals with various orientations. Whatever the orientation of the mosaic there will be extinction as the result of reflection by those individual crystals that are then in the proper position. This extinction is called secondary extinction; the range of orientation over which it occurs increases with the degree of the imperfection of the crystal.

**Efficiency of Emission of Characteristic Radiation.**—Owing to the existence of the compound photoelectric effect, the number ( $n_r$ ) of atoms that emit a certain characteristic radiation is less



than that ( $n_e$ ) of those that emit primary photoelectrons from the corresponding level. The ratio  $\phi = n_r/n_e$  may be called the efficiency of the emission of this radiation (see Table 1).

TABLE 1.—EFFICIENCY OF EMISSION OF K-RADIATION

$\phi_K$  = ratio of number of atoms that emit K-radiation to the number from which an electron is ejected from the K-level;  $Z$  = atomic number of the radiator.  $\phi_K$  is approximately independent of  $\lambda$ ;  $\phi_K > \phi_L$ .

$Z$	$\phi_K(R_L^K - 1)/R_K$			
	(227, 240)	(52)	(21)	(240)
18	0.07*			
24	0.23			
26	0.32	0.25	0.33	0.29
27	0.39	0.25		
28		0.25	0.39	0.35
29	0.42	0.25	0.44	0.40
30	0.51		0.50	0.46
34				0.59
35		0.50		0.59
36	0.51*			
42			0.83	
47		0.93	0.75	
53				0.75
54	0.70*			

\* From (13).

**Definitions** (see also preceding sections).—*Intensity of a Beam of Radiation*.—By definition, the intensity ( $I$ ,  $I_0$ ,  $I_x$ ) at any point of a beam of radiation is the power ( $P$ ) delivered at that point per unit of area ( $a$ ) normal to the direction of propagation of the beam;  $I = dP/da$ .

*Coefficients of Absorption*.—If the incident beam consists of parallel rays of a single wave-length ( $\lambda$ ) and has initially the intensity  $I_0$ , its intensity ( $I_x$ ) after passing through a thickness  $x$  is  $I_x = I_0 e^{-\mu x}$ , where  $\mu$  is a constant called the coefficient of absorption;  $\mu$  depends upon  $\lambda$ , and is characteristic of the material. As  $I = dP/da$ , and the amount of material ( $dm$ ) involved in the decrease of  $dP$  when the radiation advances from 0 to  $x$  is that contained in the volume  $x da$ , it follows that the decrease in  $I$  may be expressed in terms of  $dm/da$ ; i.e., in terms of the amount of material per unit of area, that is traversed by the radiation in going the distance  $x$ . The value of  $dm$  may be expressed in terms of any appropriate quantity, such as volume, mass, number of atoms, number ( $Z$ ) of non-nuclear electrons, number of molecules; the corresponding values of  $dm/da$  are  $x$ ,  $\rho x$ ,  $\rho N_0 x/A$ ,  $\rho N_0 Z x/A$ ,  $\rho N_0 x/M$ , and of the absorption coefficient are  $\mu$ ,  $\mu/\rho$ ,  $\mu A/\rho N_0 = \mu_a$ ,  $\mu A/\rho N_0 Z = \mu_e$ ,  $\mu M/\rho N_0 = \mu_m$ , which are called the coefficient of absorption, of mass absorption, of atomic absorption, of electronic absorption, and of molecular absorption, respectively.

The part of  $\mu$  that is due to the photoelectric effect is denoted by  $\tau$  (the coefficient of fluorescent or of photoelectric absorption), and that due to scattering, by  $\sigma$  (the coefficient of scattering);  $\mu = \tau + \sigma$ . In the scattering process, part of the power lost by the primary beam reappears as scattered radiation, the rest is absorbed by recoil electrons. The part of  $\sigma$  that is due to the former is denoted by  $\sigma_s$  (the coefficient of true scattering), that due to the latter, by  $\sigma_a$  (the coefficient of true absorption due to scattering);  $\sigma = \sigma_s + \sigma_a$ .

*Effective Wave-length*.—It has become customary, especially in the therapeutic use of X-rays, to speak of the effective wave-length of a beam of heterogeneous radiation. Duane (141) defines

it as the wave-length of that beam of homogeneous radiation which, on passing through 0.5 mm of copper, is reduced in intensity by the same fractional amount as the heterogeneous beam would be, under the same conditions. It might also be defined as the wave-length of that beam of homogeneous radiation which would be reduced to half its intensity on passing through such a thickness of copper as will produce the same reduction in the heterogeneous beam. Allen (6) deduces an effective wave-length of strongly filtered "end" radiation from the equation  $(\mu/\rho)_{Al} = 14\lambda^{2.93}$ , where  $(\mu/\rho)_{Al}$  refers to the absorption of such "end" radiation in Al, and  $2 \text{ \AA} < \lambda < 4 \text{ \AA}$ . This gives too small a value for  $\lambda$ .

In no case does the effective wave-length alone define the characteristics of the beam; it must always be considered in con-

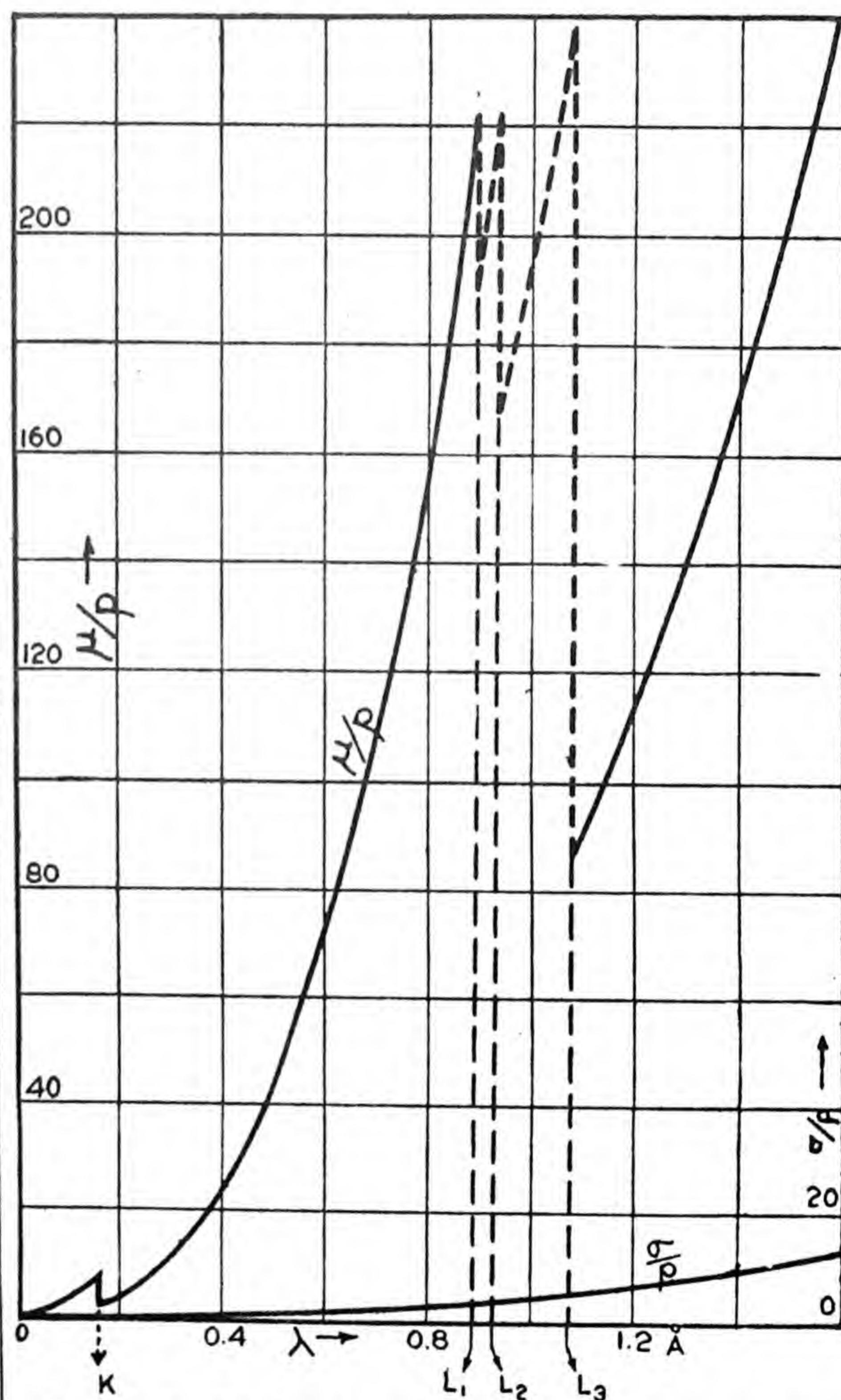


FIG. 1.—Coefficients of absorption and scattering of Pt: variation with wave-length ( $\lambda$ ). Unit of  $\mu/\rho$  and  $\sigma/\rho = 1 \text{ cm}^2/\text{g}$ .  $K$ ,  $L_{11}$ ,  $L_{21}$ ,  $L_{22}$  indicate the positions of the corresponding absorption-limits.

nection with the source and previous filtering of the beam. The more heterogeneous the beam, the less significant is the term "effective wave-length."

The views expressed above are not in agreement with those of experimenters who have observed the J-phenomena (cf. p. 1). Internal absorption of  $\gamma$ -rays is not dealt with here.



## ABSORPTION

For apparent absorption of  $\gamma$ -rays, see p. 20

A magnetic field produces no effect upon the absorption (41, 42, 100, 330). An increase in temperature has a small effect, the sign depending upon the wave-length (261). Unless  $\lambda$  is small,  $\sigma$  is very much smaller than  $\tau$ , and its variation with  $\lambda$  is negligible as compared with that of  $\tau$  (cf. p. 16). This will be the case for many of the data that will be considered.

The coefficient of mass absorption of a mixture can be computed by means of the simple additive relation  $m(\mu/\rho) = m_1 \times (\mu/\rho)_1 + m_2(\mu/\rho)_2 + \dots$ , where  $m, m_1, m_2, \dots$  are the masses of the mixture and its several components;  $m = m_1 + m_2 + \dots$ .

The coefficient of molecular absorption ( $\mu_m = \mu M/\rho N_0$ ) of many compounds can be similarly computed from the atomic absorptions of their constituent atoms (v. (16-19, 250, 317, 343)):  $\mu_m = n_1(\mu_a)_1 + n_2(\mu_a)_2 + \dots$ , where  $M = n_1A_1 + n_2A_2 + \dots$ . This expression for  $\mu_m$  is not universally correct; v. (16-19, 245); for example, for values of  $\lambda$  between 40 and 80 Å, Holweck (193, 194) found  $\mu/\rho$  to be the same for celluloid as for hydrogen.

**Variation with Wave-length and Absorber.**—For any given material the variation of  $\mu$  with  $\lambda$  exhibits certain discontinuities (see Fig. 1); the values of  $\lambda$  at which they occur are called the absorption limits of the material, and each has been found to be the longest wave-length capable of exciting a certain X-ray series characteristic of the material (cf. p. 23). The discontinuities are not absolutely sharp, but the entire change occurs within a very narrow range of wave-lengths (0.01 Å) (326); cf., however (268, 271).

When  $\lambda$  is kept constant and absorbers having various values of  $Z$  are used, similar discontinuities appear in the variation of  $\mu$  with  $Z$ , each occurring as  $Z$  passes from a value for which the absorption limit is greater, to one for which it is smaller, than  $\lambda$ .

The ratio of the maximum to the minimum value of  $\tau$  at any group of discontinuities may be called the value of the discontinuity at that limit. It is not known accurately, partly owing to the difficulty of measuring  $\mu$  and partly to our ignorance of the values of  $\sigma$ . At the  $K$ -limit the value of the discontinuity, which may be signified by  $R_L^K$  (v. (269)), is of the same order as  $\lambda_L/\lambda_K$ , where  $\lambda_K, \lambda_L$  are the wave-lengths of the  $K$ - and of the shortest ( $L_{11}$ ) of the  $L$ -absorption limits.

TABLE 2.—VALUES OF THE  $\tau$ -DISCONTINUITY ( $R_L^K$ ) AT THE  $K$ -LIMIT  
Unit of  $\lambda = 1 \text{ Å} = 10^{-8} \text{ cm}$

Absorber	$\lambda_K$	$\lambda_{L_{11}}$	$\lambda_L/\lambda_K$	$R_L^K$	Lit.
26Fe.....	1.738	14.6	8.4	9.5	(6)
28Ni.....	1.489	12.1	8.1	9.0	(6)
29Cu.....	1.379	11.0	8.0	9.1	(6)
30Zn.....	1.296	10.2	7.9	8.8	(6)
42Mo.....	0.618	4.30	7.0	7.3	(6)
				7.5	(269)
46Pd.....	0.506	3.42	6.8	6.8	(315)
47Ag.....	0.485	3.26	6.7	7.3	(6)
				7.8	(269)
50Sn.....	0.424	2.77	6.5	6.7	(315)
				6.9	(6)
				6.6	(269)
				6.1	(315)
74W.....	0.178	1.024	5.8	6.2	(6)
				5.55	(269)
78Pt.....	0.158	0.892	5.6	6.0	(6)
79Au.....	0.152	0.861	5.6	5.8	(6)
				5.65	(269)
82Pb.....	0.139	0.780	5.6	5.0	(6)
				5.4	(269)

Between adjacent absorption limits,  $\mu$  and  $\tau$  vary continuously with  $\lambda$  (cf. Table 5). None of the theoretical formulae express

this relation satisfactorily. De Broglie's formula (70), which may be put in the form

$$\tau_a = \frac{\pi e^2}{m_0 c^2} \lambda^3 \left\{ \frac{n_K}{\lambda_K^2} + \frac{n_L}{\lambda_L^2} + \dots \right\} \times 10^{-8}$$

gives, for  $\lambda < \lambda_K$ ,  $\tau_a(\text{Cu}) = 9.9\lambda^3(10)^{-21}$  and  $\tau_a(\text{Bi}) = 1.1\lambda^3(10)^{-18}$ , the approximate experimental values being  $1.5\lambda^3(10)^{-20}$  and  $1.0 \times \lambda^3(10)^{-18}$ . It also gives  $R_L^K$  a value that is twice as great as the one observed (269). Formulae, differing from de Broglie's by a numerical factor only, have been obtained by Thomson (319) and Compton (104). From Kramer's (230) formula

$$\tau_a = \frac{64\pi^4}{3\sqrt{3}} \cdot \frac{e^{10} m_0}{c^4 h^6} \left( \frac{n_K}{1.2} + \frac{n_L}{2^{1/2} \cdot 3} + \frac{n_m}{3^{1/2} \cdot 4} + \dots \right) Z^4 \lambda^3 (10)^{-24}$$

we get  $\tau_a = 1.2\lambda^3 Z^4 (10)^{-26}$ , if  $\lambda < \lambda_K$ , and  $R_L^K = 5.5$ ; the value of  $\tau_a$  is about 40% too low. By applying the methods of Schrödinger's wave mechanics, Wentzel (331) has obtained for the absorption due to the  $K$ -electrons the expression

$$\tau_a = \frac{32}{3} \cdot \frac{e^2}{m_0 c^2} \left( \frac{\lambda}{\lambda_K} \right)^{5/2} \left\{ 3\sqrt{\lambda} \cos \psi + \sqrt{\lambda_K} \sin \psi \right\}^2 (10)^{-8}$$

where  $\psi$  is an undetermined phase angle, which may depend on  $\lambda$  and  $Z$ .

Several empirical formulae have been deduced, mostly of the form  $\tau_a = CZ^m \lambda^n (10)^{-26}$ , where  $m$  and  $n$  are approximately equal to 4 and 3, respectively, and  $C$  changes as  $\lambda$  passes through an absorption limit. No values yet proposed for  $C$ ,  $m$ , and  $n$  are entirely satisfactory, especially when  $\lambda < 0.1 \text{ Å}$ ; those most used are given in Table 3,  $m$  being taken as 4. The best are those given by Gray, but those by Richtmyer and Richtmyer and Warburton are the most generally accepted, although derived from a small range of observations.

TABLE 3.—VALUES OF  $C$  AND  $n$  IN  $\tau_a = CZ^4 \lambda^n (10)^{-26}$   
Unit of  $\lambda = 1 \text{ Å} = 10^{-8} \text{ cm}$

Range	$\lambda < \lambda_K$		$\lambda_K < \lambda$ $< \lambda_{L_{11}}$		$\lambda_{L_{11}} < \lambda$ $< \lambda_{M_{11}}$		Lit.
Author	$C$	$n$	$C$	$n$	$C$	$n$	
R. and W.*.....	2.24	3	0.33	3			(266, 272)
Allen.....	2.18	2.92	0.299	2.92			(5)
Gray.....	1.92 $P^\dagger$	3	0.255	2.7	0.058	2.6	(175)

\* Richtmyer and Warburton.

†  $P = (1 + 0.008Z) \left\{ 1 - \frac{\lambda}{4\lambda_K} - \frac{\lambda}{50\lambda_K} \right\}$ ,  $\lambda$  and  $\lambda_K$  being expressed in Ångströms.

Jönsson (Diss., Upsala, 1928) has shown that, to a high degree of approximation

$$\tau/\rho = \frac{Z}{A} \cdot \frac{\lambda_K}{\lambda_c} \cdot f(Z\lambda)$$

for values of  $Z\lambda > 8$  and  $\lambda < 12 \text{ Å}$ .  $\lambda_c$  is the nearest critical absorption wave-length  $> \lambda$ . Jönsson tabulates values of the function  $f(Z\lambda)$ . We may write  $f(Z\lambda) = (Z\lambda)^x$  where  $x = 2.03 - 10/Z\lambda + 100/Z^2 \lambda^2$ . This formula and the first of Gray's may be used to give an approximate check on experimental results and to deduce unknown values of  $\tau/\rho$ . Jönsson's generalization is not true for values of  $Z\lambda < 8$  nor for a light element such as carbon.

TABLE 4.—COEFFICIENTS OF ABSORPTION FOR  $\lambda = 0.586, 0.631$   
AND  $0.709 \text{ Å}$

All substances for which either  $\mu/\rho$  or  $\mu_m$  is given in this section are here listed, with references to all sources utilized in determining any of these values; references to other data are placed after "cf." For certain substances, values of  $\mu/\rho$  or of  $\mu_m$  are given for no other  $\lambda$ ; no additional data for absorption at these  $\lambda$ 's are given elsewhere in this section. Substances are listed in the order: Elements, inorganic compounds, organic compounds. Italics indicate the value of  $\mu/\rho$  that next precedes a known absorption-limit.  $Q = (Z/29)^4$ , 29 is  $Z$  for Cu (cf. Table 3);  $\mu_m = \mu M/\rho N_0 = (k\mu/\rho) \times 10^{-23}$ , where  $M$  = molecular weight as



indicated by the formula,  $N_0 = 6.061 \times 10^{23}$  molecule per g-mole. Unit of  $\lambda = 1 \text{ \AA} = 10^{-8} \text{ cm}$ ; of  $\mu/\rho = 1 \text{ cm}^2/\text{g}$ ; of  $\mu_m = 10^{-22} \text{ cm}^2$  per molecule; of  $k = 10^{-22} \text{ g}$  per molecule.

$\lambda$			0.586	0.631	0.709	Lit.
(1)	Q	k	$\mu/\rho$			
Ag47.....	6.91	17.80	15.5	19.4	26.2	(4, 5, 6, 266, 269, 316); cf. (1, 65, 215, 255, 343)
Al13.....	0.040	4.45	3.00	3.70	5.21	(4, 5, 6, 239, 266); cf. (1, 65, 144, 177, 189, 197, 215, 255, 256, 316, 317, 343)
Au79.....	55.1	32.54	75.0		122	(4, 5, 6, 269); cf. (65, 216, 343)
Ba56.....	13.91	22.67	26.3		41.3	(5); cf. (343)
Bi83.....	67.1	34.48	See Table 5			(5); cf. (1)
Br35.....	2.12	13.19	45.3		67.2	(343); cf. (301)
C8.....	0.0018	1.980	0.450* 0.382†	0.550* 0.435†	0.630* 0.550†	(4, 5, 6, 189); cf. (1, 215, 250, 301, 317, 343)
Ca20.....	0.23	6.61	10.9		19.7	(343)
Cd48†.....	7.51	18.55	17.5		30.3	(343)
Cl17.....	0.12	5.85	6.9		11.9	(343); cf. (301)
Co27.....	0.75	9.73	22.6		38.9	(272, 343)
Cr24.....	0.47	8.58	18.1		29.6	(343)
Cu29.....	1.00	10.49	29.0	36.7	51.0	(4, 5, 6, 239, 266, 272, 315); cf. (1, 65, 144, 177, 197, 215, 327, 343)
Fe26.....	0.65	9.21	23.1	27.9	37.6	(4, 5, 6, 239, 272); cf. (1, 65, 189, 198, 215, 343)
H1‡.....	$1.4 \times 10^{-3}$	0.1663	0.381	0.388	0.401	(17, 250, 297); cf. (1)
I53.....	11.15	20.94	22.8		39.4	(343); cf. (301)
K19.....	0.18	6.45	9.1		16.1	(343)
Li3.....	$11 \times 10^{-3}$	1.145	0.300	0.360		(189)
Mg12.....	0.029	4.01			4.1	(4); cf. (215, 256, 343)
Mn25.....	0.55	9.06	19.2		34.4	(343)
Mo42.....	4.40	15.84	75.0	13.8	19.5	(266, 269); cf. (215, 343)
N7.....	0.0034	2.31			1.1	(189); cf. (193, 194, 343)
Na11.....	0.021	3.80	2.09		3.40	(343)
Ni28.....	0.87	9.68	28.9	34.8	45	(4, 5, 6, 239, 272); cf. (65, 215, 260, 343)
Os.....	0.058	2.64	0.71	0.850	1.13	(189); cf. (1, 193, 194, 250, 301, 317, 343)
Pb82.....	63.9	34.19	74.5	101	140	(4, 5, 6, 269); cf. (1, 65, 177, 197, 199, 256, 343)

\* (5).

† (189); values agree with those obtained from liquids; cf. (266).

‡ For Cd,  $\mu/\rho = 5.48$  for  $\lambda = 0.188$ .

§ Values of  $\mu/\rho$  are computed, see Table 5.

$\lambda$			0.586	0.631	0.709	Lit.
(1)	$Q$	$k$	$\mu/\rho$			
Pd46.....	6.33	17.60		17.2	23.8	(315); cf. (65)
Pt78.....	52.3	32.21	73.5	87.0	117	(4, 5, 6); cf. (1, 65, 215, 343)
Rh45  .....	5.80	16.98	15.2			(322, 343)
S16.....	0.093	5.29	5.90	6.90	9.80	(4, 5); cf. (301, 343)
Sn50.....	8.84	19.59	18.7	22.6	32.1	(4, 5, 6, 269); cf. (1, 65, 177, 215, 256, 343)
Sr38.....	2.95	14.48	57.7		94.3	(343)
Th90.....	92.8	38.30	See Table 5			(5); cf. (1)
U92.....	101	39.30		88	121	(5); cf. (1, 315)
W74.....	42.4	30.36	56.8	75.0		(5, 269); cf. (343)
Yt39.....	3.27	14.68	60.3		99.9	(343)
Zn30.....	1.15	10.79	34.3	43.0	59.0	(5, 6); cf. (1, 65, 177, 215, 256, 343)
Zr40.....	3.62	15.02			19.7	(343)

$\lambda$		0.586		0.709		Lit.
Substance	$k$	$\mu_m$	$\mu/\rho$	$\mu_m$	$\mu/\rho$	
Air.....		See Table 5				(215); cf. (165)
H <sub>2</sub> O.....	2.972	2.04	0.686	3.21	1.08	(189, 250, 266); cf. (317, 343)
HCl.....	6.017	40.8	6.77	70.95	11.8	(343)
SO <sub>2</sub> .....	10.57	See Table 5				(315); cf. (165)
H <sub>2</sub> SO <sub>4</sub> .....	16.18	39.3	2.43	56.43	3.48	(343)
N <sub>2</sub> H <sub>4</sub> .....	5.188	See Table 5				(19, 29)
NH <sub>4</sub> NO <sub>3</sub> .....	13.21			13.53	1.02	(343)
H <sub>3</sub> PO <sub>4</sub> .....	16.18	32.7	2.02	53.46	3.34	(343)
CO <sub>2</sub> .....	7.26	See Table 5				(215); cf. (165)
Zr(SO <sub>4</sub> ) <sub>2</sub> .....	46.72			407.7	8.73	(343)
Pb(NO <sub>3</sub> ) <sub>2</sub> .....	54.65	2563.0	46.9	3496.4	64.0	(343)
ZnCl <sub>2</sub> .....	22.49	448.9	19.5	729.3	32.34	(343)
ZnSO <sub>4</sub> .....	26.64	404.9	15.2	656.6	24.6	(343)
CdCl <sub>2</sub> .....	30.25	404.8	13.3	701.2	23.2	(343)
CuCl <sub>2</sub> .....	22.19	386.4	17.4	630.0	28.4	(343)
CuSO <sub>4</sub> .....	26.34	339.7	12.9	542.2	20.5	(343)
AgNO <sub>3</sub> .....	28.03	299.7	10.6	558.6	19.9	(343)
MnCl <sub>2</sub> .....	20.76	255.4	12.3	451.7	21.7	(343)
FeCl <sub>3</sub> .....	26.76	325.5	12.2	556.2	20.8	(343)
CoCl <sub>2</sub> .....	21.43	302.2	14.1	507.4	23.7	(343)
NiCl <sub>2</sub> .....	21.39	325.0	15.2	603.4	28.2	(343)
CrCl <sub>2</sub> ·4H <sub>2</sub> O.....	38.02	284.4	7.48	474.5	12.5	(343)
(NH <sub>4</sub> ) <sub>2</sub> MoO <sub>4</sub> .....	32.35			341.3	10.6	(343)
U <sub>3</sub> O <sub>8</sub> .....	139.0	See Table 5				(315)
Yt(NO <sub>3</sub> ) <sub>3</sub> .....	45.38	898.5	19.8	1492.7	32.9	(315)
MgCl <sub>2</sub> .....	15.72			155.4	9.89	(343)
CaCl <sub>2</sub> .....	18.31	152.7	8.34	270.3	14.7	(343)
SrCl <sub>2</sub> .....	26.16	935.1	35.7	1503.5	57.5	(343)
Sr(NO <sub>3</sub> ) <sub>2</sub> .....	34.92	844.6	24.3	1380.0	39.5	(343)
BaCl <sub>2</sub> .....	34.37	677.0	19.7	1074.7	31.3	(343)
NaOH.....	6.60			15.51	2.35	(343)
NaCl.....	9.64	48.43	5.01	76.10	7.89	(343)
NaBr.....	16.98	605.2	35.6	899.2	53.0	(343)
NaI.....	24.74	485.4	19.6	838.5	34.3	(343)
Na <sub>2</sub> RhCl <sub>6</sub> .....	63.47	522.4	8.24			(343)
Na <sub>2</sub> MoO <sub>4</sub> .....	30.21	1158	38.3			(343)
Na <sub>2</sub> WO <sub>4</sub> .....	48.51	1747.0	36.0			(343)
KCl.....	12.30	99.4	8.08	173.4	14.1	(343)
Mica.....		See Table 5				(322)

Formula	Substance ( $\lambda = 0.709$ )	k	$\mu_m$	$\mu/\rho$	Lit.
CH <sub>3</sub> I	Methyl iodide.....	23.42	See Table 5		(215); cf. (165)
C <sub>2</sub> H <sub>5</sub> O <sub>2</sub>	Methyl formate.....	7.27	See Table 5		(19, 29)
C <sub>2</sub> H <sub>5</sub> Br	Ethyl bromide.....	17.98	See Table 5		(215); cf. (165)
C <sub>2</sub> H <sub>5</sub> O	Acetone.....	9.58	6.62	0.691	(317)

|| For Rh,  $\mu/\rho = 14.2, 15.1, 17.7$  if  $\lambda = 0.545, 0.586, 0.612$ , respectively.



TABLE 4.—(Continued)

Formula	Substance ( $\lambda = 0.709$ )	$k$	$\mu_m$	$\mu/\rho$	Lit.
C <sub>3</sub> H <sub>6</sub> O	Acetone.....	9.58	7.54	0.787	(343)
C <sub>3</sub> H <sub>8</sub> O	Allyl alcohol.....	9.58	See Table 5		(19, 20)
C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	Ethyl formate.....	12.22	9.70	0.794	(317)
C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	Propionic acid.....	12.22	10.2	0.833	(343)
C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	Propionic acid.....	12.22	See Table 5		(19, 20)
C <sub>3</sub> H <sub>6</sub> O <sub>3</sub>	Dimethyl carbonate.....	14.86	See Table 5		(19, 20)
C <sub>3</sub> H <sub>8</sub> O	Isopropyl alcohol.....	9.91	6.84	0.690	(317)
C <sub>3</sub> H <sub>8</sub> O <sub>2</sub>	Trimethyleneglycol.....	12.55	9.86	0.786	(317)
C <sub>4</sub> H <sub>8</sub> O	Methyl ethyl ketone.....	11.89	See Table 5		(19, 20)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Ethyl acetate.....	14.53	11.55	0.795	(317)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Ethyl acetate.....	14.53	See Table 5		(19, 20)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Methyl propionate.....	14.53	11.44	0.787	(317)
C <sub>6</sub> H <sub>6</sub>	Benzene.....	12.88	7.07	0.549	(317)
C <sub>6</sub> H <sub>6</sub>	Benzene.....	12.88	6.93	0.538	(250); cf. (317)
C <sub>6</sub> H <sub>12</sub> O	Cyclohexanol.....	16.52	10.5	0.634	(250)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Paraldehyde.....	21.80	17.3	0.794	(343)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Paraldehyde.....	21.80	See Table 5		(19, 20)
C <sub>7</sub> H <sub>8</sub>	Toluene.....	15.19	8.35	0.550	(317)
C <sub>7</sub> H <sub>8</sub>	Toluene.....	15.19	8.13	0.535	(250); cf. (317)
C <sub>7</sub> H <sub>8</sub>	Toluene.....	15.19	See Table 5		(19, 20)
C <sub>7</sub> H <sub>8</sub> O	Benzyl alcohol.....	17.83	See Table 5		(19, 20)
C <sub>7</sub> H <sub>16</sub>	n-Heptane.....	16.52	8.77	0.531	(250)
C <sub>8</sub> H <sub>10</sub>	n-Xylene.....	17.50	9.40	0.537	(250)
C <sub>8</sub> H <sub>18</sub>	Octane.....	18.83	See Table 5		(19, 20)
C <sub>8</sub> H <sub>18</sub> O	Octyl alcohol.....	21.47	See Table 5		(19, 20)
C <sub>9</sub> H <sub>12</sub>	Mesitylene.....	19.82	10.6	0.534	(250)
C <sub>10</sub> H <sub>16</sub>	Limonene.....	22.46	12.06	0.537	(317)
C <sub>10</sub> H <sub>16</sub>	Pinene.....	22.46	12.08	0.538	(317)
	Celluloid.....		See Table 5		(244); cf. (193, 194)
	Gelatin.....		See Table 5		(205)

TABLE 5.—COEFFICIENTS OF ABSORPTION OF X-RAYS AND  $\gamma$ -RAYS

For apparent coefficients of absorption of  $\gamma$ -rays, see Tables 12, 13, 14; for coefficients of absorption by those substances for which there are no data except for  $\lambda = 0.586$ , 0.631, or 0.709 Å, see Table 4.

The data in this table are believed to be the best available; many of them are averages of graphical values given in the sources listed in Table 4; all are founded on experimental values. Owing to frequent wide variations in the values obtained by different observers, it is difficult to make a useful estimate of the accuracy of the data. For wave-lengths greater than 2 Å, strongly filtered "end" radiations have been used. As the tabulated value of  $\lambda$  is the effective  $\lambda$  defined by Allen's equation  $(\mu/\rho)_{\lambda} = 14 \lambda^{2.32}$ , it is too small; the corresponding values of  $\mu/\rho$  are not accurate when this effective  $\lambda$  is near an absorption limit. In fact, all the given values of  $\mu/\rho$  for wave-lengths near the  $L$  and  $M$  absorption-limits are liable to be inaccurate. For additional data for  $\lambda > 2$  Å, see (193, 194, 233). In general, see Table 4 for literature references.

Italics indicate the value of  $\mu/\rho$  that next precedes a known absorption-limit. Substances are listed in the order: Elements, inorganic compounds, organic compounds; and the first is divided into the sections:  $\gamma$ -rays,  $\lambda = 0.08$  to 0.11 Å,  $\lambda = 0.1$  to 1.0 Å,  $\lambda = 1.0$  to 3.9 Å, and radiation specified solely by the tube voltage. The symbol of an element is followed by its atomic number ( $Z$ );  $Q = (Z/29)^4$ , 29 is  $Z$  for Cu (cf. Table 3);  $\mu_{\alpha} = \mu A/\rho N_0 = (k\mu/\rho) \times 10^{-23}$ ,  $\mu_m = \mu M/\rho N_0 = (k\mu/\rho) \times 10^{-23}$ , where  $A$  = atomic weight,  $M$  = molecular weight as indicated by the formula,  $N_0 = 6.061 \times 10^{23}$  molecule per g-mole;  $V$  = potential difference of terminals of the tube. Unit of  $\lambda = 1$  Å =  $10^{-8}$  cm; of  $\mu/\rho = 1$  cm<sup>2</sup>/g; of  $\mu_m = 10^{-23}$  cm<sup>2</sup> per molecule; of  $k = 10^{-23}$  g per molecule; of  $V = 1000$  volt.

I.  $\gamma$ -rays of Ra(B and C) filtered through  $x$  cm of Pb\*

Symbol.....	Al13	Cu29	Fe26	Mg12	Pb82	Sn50	Zn30	Lit.
$Q$ .....	0.040	1.00	0.65	0.029	63.9	8.84	1.15	
$k$ .....	4.45	10.49	9.21	4.01	34.19	19.59	10.79	
$x$	$\mu/\rho$							Lit.
5.35		0.0450			0.0480			(177)
4.30		0.0452			0.0487			(177)
3.25		0.0460			0.0513			(177)
2.2	0.0559			0.0566	0.0633	0.0525	0.0567	(256)
2.2	0.0486	0.0479			0.0552	0.0448	0.0466	(177)
1.5			0.0632		0.0727			(198)
1.0	0.0514				0.0626	0.0498		(352)
1.0		0.0510			0.0630			(177)
0.3	0.0560				0.0830			(177)

\*For further data on  $\gamma$ -rays, see (1, 2).

## II. X-rays

$\lambda$			0.081	0.085	0.090	0.095	0.100	0.110	
(1)	$Q$	$k$	$\mu/\rho$						
Ag47.....	6.91	17.8	0.740	0.830	0.900	1.02	1.12	1.32	
Al13.....	0.040	4.45	0.145	0.153	0.160	0.165	0.167	0.171	
Au79.....	55.1	32.54	2.44	2.65	2.85	3.30	3.60	4.28	
Bi83.....	67.1	34.48	2.25	2.76	3.00	3.45	3.75	4.50	
C6.....	0.0018	1.98	0.143	0.145	0.148		0.150		
Cu29.....	1.00	10.49	0.270		0.295		0.335	0.390	
Fe26.....	0.65	9.21	0.235		0.252		0.285	0.325	
Ni28.....	0.87	9.68	0.265		0.290		0.340	0.385	
Pb82.....	63.9	34.19	2.53	2.78	3.00	3.46	3.77	4.46	
Pt78.....	52.3	32.21	2.50	2.75	2.95	3.38	3.65	4.35	
Si16.....	0.093	5.29	0.155	0.170	0.182	0.186	0.190	0.195	
Sn50.....	8.84	19.59	0.80	0.88	0.95		1.16	1.45	
U92.....	101	39.30				3.53			
W74.....	42.4	30.36	2.40	2.60	2.80	3.10	3.37	4.05	
Zn30.....	1.15	10.79	0.310		0.350		0.375	0.450	
Symbol.....	Ag47	Al13	Au79	Au79	Ba56	Bi83	C6	Co27	Cu29
$Q$ .....	6.91	0.040	55.1	(269)	13.91	67.1	0.0018	0.75	1.00
$k$ .....	17.8	4.45	32.54		22.67	34.48	1.98	9.73	10.49
$\lambda$	$\mu/\rho$								
0.100	1.12	0.167	3.60	3.08		3.75	0.150	0.304*	0.335
0.110	1.32	0.171	4.28	3.81		4.50		0.345*	0.390
0.120	1.55	0.175	5.06	4.71	2.00†	4.90†			0.460
0.130	1.85	0.185	5.90	5.75					0.545
0.140	2.20	0.195	6.90	6.96	2.80†			0.521*	0.640
0.145			7.40	7.55		2.25			
0.150	2.60	0.205			3.40†	2.44	0.153	0.75‡	0.750
0.160	3.05	0.215	2.63	2.47	4.00†	2.90		0.687*	0.880
0.170	3.55	0.225	2.88		4.65†	3.32			1.03
0.180	4.10	0.235	3.30	3.16	5.40†	3.86		0.903*	1.18
0.190	4.75	0.246	3.76		6.47†	4.42		1.24‡	1.34
0.200	5.47	0.267	4.25	4.11	7.45†	5.10	0.164	1.17*	1.51
0.220	7.20	0.302	5.50		9.20†	6.48		1.72‡	1.90
0.240	9.20	0.349	6.95		11.7†	8.30	0.170	1.90*	2.41
0.260	11.6	0.405						2.53‡	2.99
0.280	14.3	0.467			17.2†	12.5		2.90*	3.68
0.300	17.2	0.537		11.7			0.195	3.53*	4.38
0.320	20.4	0.623			24.2†	17.7			5.11
0.340	23.9	0.720			6.00	21.0	0.210		6.20
0.360	28.0	0.835							7.30
0.380	32.5	0.950							8.55
0.400	37.2	1.08			9.00		0.243		9.85
0.420	42.4	1.23							11.3
0.440	48.1	1.38			12.2		0.270		12.9
0.450	50.2						0.280		
0.460		1.54			14.0		0.288		14.6
0.480		1.72	51.7‡				0.300		16.4
0.500	9.55	1.95			17.8		0.325¶		18.4
0.550	13.0	2.46					0.378¶		24.2
0.586	15.5	3.00	64.5**	75.0††	26.3**		0.450¶	22.6‡	29.0
0.631	19.4	3.70					0.550¶		36.7
0.709	26.2	5.21	122		41.3**		0.630¶	38.1‡	51.0
0.748	33.0	6.20	141				0.750¶		60.0
0.910	57.0	10.8	165				1.25¶		102
1.000	73.0	14.2	110				1.50¶		133

\* Calculated (219) from  $\mu/\rho = 124\lambda^2 + 0.18$  if  $0.1 < \lambda < 0.3$ .

† Probably too low.

‡ Value for  $\lambda = 0.118$ .

§ From (343); too great if  $0.150 < \lambda < 0.254$ .

|| Used  $K$ -radiation of a suitable substance (215); some of the values tabulated for Mg were obtained by interpolation.

\*\* These values (5) do not agree even approximately with data for compounds; other data (189) are in very good agreement, cf. (250).



TABLE 5. II.—(Continued)

Symbol.....	Fe26	H11†	Li3	Mg12	Mo42‡§	N7	Ni28	O8	Pb82
Q.....	0.65	$1.4 \times 10^{-6}$	$11 \times 10^{-8}$	0.029	4.40	0.0034	0.87	0.058	63.9
k.....	9.21	0.1663	1.145	4.01	15.84	2.31	9.68	2.64	34.19
$\lambda$	$\mu/\rho$								
0.100	0.285	0.300					0.340	0.150	3.77
0.110	0.325						0.385		4.46
0.120	0.370			0.160			0.440		5.28
0.130	0.425			0.165			0.510		6.20
0.140	0.490			0.170			0.595		
0.150	0.565			0.175	1.93	0.160	0.690	0.160	2.37
0.160	0.645			0.186	2.32		0.795		2.70
0.170	0.735			0.196	2.72		0.930		3.10
0.180	0.830			0.207	3.10		1.07		3.55
0.190	0.940			0.220	3.52		1.23		4.05
0.200	1.07	0.316		0.232	4.02	0.180	1.40	0.180	4.62
0.220	1.38			0.260	5.20		1.77		5.85
0.240	1.72	0.323		0.293	6.60	0.197	2.22	0.204‡§	7.35
0.260	2.16	0.326		0.330	8.25		2.80		9.20
0.280	2.68			0.375	10.10		3.40		11.3
0.300	3.23	0.333	0.175	0.430	12.4	0.222	4.10	0.243‡§	13.6
0.320	3.90			0.480	15.0		4.85	0.259‡§	16.2
0.340	4.60	0.340	0.180	0.570	17.7	0.248	5.75		19.7
0.360	5.35	0.343		0.660	20.5		6.70		23.0
0.380	6.26			0.760	23.6				27.2
0.400	7.24	0.350	0.210	0.875	27.0			0.336‡§	31.8
0.420	8.0‡‡			0.995	30.5				36.5
0.440			0.225	1.13	34.0			0.385	41.2
0.450		0.358							
0.460				1.27	38.7				46.5
0.480				1.40	44.0				53.0
0.500	14.8††	0.366	0.250		48.6		18.5††	0.500	58.0
0.550	19.8††		0.275		63.8		24.4††		
0.586	23.1††	0.381	0.300		75.0††¶		28.9††	0.71	74.5‡‡
0.631	27.9††	0.388	0.361		13.8		34.8††	0.85	101
0.709	37.6	0.401		4.1‡‡	19.5	1.1‡‡	45	1.13	140
0.748	44.5	0.408			23.0		53	1.31‡§	146
0.810	74.5	0.425			39.5		86	2.27‡§	160
1.000	101	0.450			50.4		115	2.95‡§	77

Symbol.....	Pd46	Pt78	S16	Sn50	Th90	U92***	W74	W74	Zn30
Q.....	6.33	52.3	0.093	8.84	92.8	101	42.4	42.4	1.15
k.....	17.60	32.21	5.29	19.59	38.30	39.30	30.36	(269)	10.79
$\lambda$	$\mu/\rho$								
0.100		3.65	0.190	1.16	4.0		3.37	2.67	0.375
0.110		4.35	0.195	1.45			4.05	3.29	0.450
0.120		5.14	0.200	1.80		1.87	4.83	4.03	0.530
0.130		6.05	0.225	2.20	1.96	2.27	5.72	4.93	0.630
0.140		7.08	0.250	2.60	2.25	2.56	6.75	5.91	0.750
0.145		7.55			2.48				
0.150			0.272	3.05	2.66	2.99	7.90	7.10	0.880
0.160			0.295	3.55	3.10	3.41	8.90	8.47	1.02
0.170		2.84	0.320	4.10	3.61			9.89	1.20
0.180		3.24	0.350	4.65	4.16				1.38
0.190		3.70	0.385	5.30	4.78		3.06		1.56
0.200		4.16	0.420	6.00	5.42		3.49		1.79
0.220		5.25	0.500	7.90	6.90		4.25		2.32
0.240		6.60	0.580	10.2	8.60		5.23		2.80
0.260			0.680	12.6			6.30		3.50
0.280		9.60	0.800	15.3			7.60		4.30
0.300	16.2	11.5	0.930	18.2			8.90		5.20
0.320		13.5	1.08	21.5			10.4		6.20
0.340	22.0	15.8	1.23	25.0			12.2		7.30
0.360	25.2	18.2	1.42	29.0			14.5		8.50
0.380		21.2	1.58	34.0			17.1		10.0
0.400	33.5	24.5	1.78	39.5		41	19.8		11.6
0.420		28.0	1.95				23.0		13.5

\*\* From (243).

†† From (26).

 ‡‡ Values are computed from  $\mu/\rho = 0.283 + \lambda/6$ ; for experimental values derived from observations on compounds containing H, see below (organic compounds). If  $40 < \lambda < 100$ ,  $\mu/\rho = 0.2\lambda^{1.2}$ , see (193); also (232).

§§ Interpolated from (250).

 || From value (189) 8.12 at  $\lambda = 0.422$ .

 ¶¶ For  $\lambda = 0.600$ ,  $\mu/\rho = 81$ .

 \*\*\* Values for  $0.4 < \lambda < 1.6$  are calculated from observed values (215) of  $(\mu/\rho)_\lambda/(\mu/\rho)_{0.708}$  for  $U_2O_5$  (see p. 16) on the assumptions that  $(\mu/\rho)_\lambda$  for U is proportional to  $(\mu/\rho)_\lambda$  for  $U_2O_5$ , and that for U  $\mu/\rho = 41.0$  at  $\lambda = 0.400$ .

TABLE 5. II.—(Continued)

Symbol.....	Pd46	Pt78	S16	Sn50	Th90	U92***	W74	W74	Zn30
Q.....	6.33	52.3	0.093	8.84	92.8	101	42.4	42.4	1.15
k.....	17.60	32.21	5.29	19.59	38.30	39.30	30.36	(269)	10.79
$\lambda$	$\mu/\rho$								
0.440	42.5	31.8	2.2	8.5			26.4		15.4
0.450	45.0					54			
0.460	47.7	36.0		9.6			30.0		17.5
0.480		40.5		10.9					19.7
0.500	58.7	45.5		12.0		71			22.0
0.550	11.5			15.8		93			28.1
0.586		73.5	5.90‡‡	18.7			56.8‡‡		34.3
0.631	17.2	87.0	6.90	22.6		88	75.0		43.0
0.709	23.9	117	9.8†††	32.1		123			59.0
0.748		134		39.0		57			69.0
0.810		170		66.0		92			115
1.000		165		87.0		120			152

Symbol.....	Ag47	Al13	Au79	C6	Cu29	Fe26	Mg12
Q.....	6.91	0.040	55.1	0.0018	1.00	0.65	0.029
k.....	17.80	4.45	32.54	1.98	10.49	9.21	4.01
$\lambda$	$\mu/\rho$						
1.000	73.0	14.2	110	1.50¶	133	101	
1.090	95.0	18.0	88	2.00	165	127	15.7
1.170	113	22.5	104	2.40	206	158	20.0
1.293	146	30.0	137	3.20	266	207	
1.389	173			3.80	38.0		
1.432	192	40.3	179	4.30	42.0	280	36.6
1.537	225	50.0	210	4.90	50.0	324	
1.655	280	62.0	265	6.40	63.2	424	54.6
1.752	325	73.0		7.30		56.0	
1.933	410	93.0		9.20	97.0	70.0	82.8
2.25	580	136		15.3	143	104	126
2.500†††	696	182			202		
2.744†††	925	248			262		
3.026†††	1330	320			321		
3.353†††	1310	433			404		
3.432†††	1460						
3.592†††	1360						
4.146†††	461	771			621		
4.359†††	539	894			730		
5.394†††	852	1480			1300		
6.973†††	1260	2800			2120		
8.319†††	1770	344			3450		
9.868†††	2720	553			5030		
11.889†††		767			7550		

Symbol.....	Ni28	Pb82	Pt78	Sn50	U92	W74	Zn30
Q.....	0.87	63.9	52.3	8.84	101	42.4	1.15
k.....	9.68	34.19	32.21	19.59	39.30	30.36	10.79
$\lambda$	$\mu/\rho$						
1.000	115	77	165	87.0	120		152
1.090	145	98	87	110	133		186
1.170		120	100	132			226
1.293	230	154	131	176	214	105	38.0
1.389		180	155	205			45.0
1.432	311	202	171	235	272	131	50.5
1.537	45.7	230	199	275	360		59.0
1.655	57.0	290	243	325			76.0
1.752	67.0	335	280	385	431		90.0
1.933	89.0	420	365	490	470		115
2.25	129		517				170
2.500†††	180		596				
2.744†††	239		756				
3.026†††	319		939				
3.353†††	384		1120				
3.592†††			1370				
4.146†††	627		1290				
4.359†††	735						
5.394†††	1250		1640				
6.973†††	2000		1190				
8.319†††	3140		1530				
9.868†††	4540		2440				

††† Another value (243) is 8.7.

 ‡‡‡ From Jönsson (*Disa.*, Upsala, 1928) replacing values, obtained by Allen with "end" radiations, referred to above. Objections to results obtained with  $\lambda$  in neighborhood of absorption limits are not valid here. Formula given after Table 3 can be used to calculate values of  $\mu/\rho$  for other substances.



TABLE 5. II.—(Continued)

V	Br	C	Cl	I	S
$\mu_{\alpha}/(\mu_{\alpha})_N$ (301)					
1.4	4.72	0.60	2.20	34.50	1.80
0.9	4.30	0.60	2.28		2.02

H <sub>2</sub> O, Water; $k = 2.972$								
$\lambda$	$\mu/\rho$	$\mu_m$	$\lambda$	$\mu/\rho$	$\mu_m$	$\lambda$	$\mu/\rho$	$\mu_m$
0.100	0.167	0.496	0.220	0.212	0.630	0.440	0.400	1.19
0.110	0.171	0.508	0.240	0.223	0.662	0.500	0.500	1.48
0.120	0.175	0.520	0.260	0.234	0.695	0.550	0.600	1.78
0.130	0.178	0.529	0.280	0.246	0.731	0.586	0.686	2.04
0.140	0.180	0.536	0.300	0.259	0.769	0.631	0.812	2.41
0.150	0.183	0.545	0.320	0.273	0.811	0.709	1.08	3.21
0.160	0.187	0.555	0.340	0.290	0.861	0.783	1.38	4.10
0.170	0.190	0.564	0.360	0.309	0.918	0.881	1.95	5.79
0.180	0.194	0.576	0.380	0.330	0.980	0.929	2.18	6.47
0.190	0.198	0.588	0.400	0.352	1.05	0.977	2.52	7.48
0.200	0.201	0.597	0.420	0.376	1.12			

NaCl, Rock salt crystals (62, 63); cf. (20)

$\lambda = 0.589 \text{ \AA}$ , Pl = reflecting plane,  $O$  = order of reflection,  $\epsilon$  = extinction coefficient,  $E$  = relative amount of integrated energy reflected.  $k = 9.645$ ;  $\mu = 10.70 \text{ cm}^2/\text{g}$ .

O	Pl	$\mu + \epsilon$	$\epsilon^*$	E
1	100†	16.30	5.60	100
1	110	13.60	2.90	50.5
2	200	12.66	1.96	19.9
3	300	10.72	0.02	4.87

\* Secondary extinction only.

† For plane 100, Kirkpatrick (220) finds  $\mu + \epsilon = 189\lambda^{1.5} + 0.43$  and  $\epsilon = 1.90\lambda^{1.5}$ , if  $0.24 < \lambda < 0.58$ .

Substance	Air	CO <sub>2</sub>	SO <sub>2</sub>	CH <sub>4</sub> †	C <sub>2</sub> H <sub>6</sub> Br*	U <sub>3</sub> O <sub>8</sub> (315)
1000p	1.29	1.98	2.88	6.38	4.90	$\lambda_1 = 0.708$
k		7.26	10.57	23.42	17.98	

$\lambda$	$\mu/\rho$ (215)†					$\lambda$	$(\mu/\rho)_{\lambda}$
							$(\mu/\rho)_{\lambda_1}$
KAg0.555	0.59		2.75	17.7	22.0	0.400	0.340
KMo0.692	0.98	1.42	5.56	30.9	42.9	0.450	0.450
KBr0.855	1.78	2.12	9.76	53.0	66.3	0.500	0.590
KBr1.02	3.02		17.4	86.5	19.6	0.550	0.770
KBr1.08	3.40	3.96	19.1	97	22.4	0.600	0.640
KAs1.15	4.10	5.00	22.9	116	26.1	0.631	0.730
KZn1.40	6.96	9.31	38.9	198	43.9	0.708	1.000
KCu1.51	8.43	11.5	46.5	241	53.1	0.750	0.480
KNi1.61	10.5	16.1	57.6	282	66.3	0.800	0.560
KCo1.75	12.7		69.4		83.2		
KFe1.90	15.6	23.1	83.3	339	105		

\* Values of  $\mu$  are probably too small.

† Gowdy's values (165) differ from these.

Mica (322)

Line	KAg $\beta$	KRh $\beta$	KAg $\alpha$	KRh $\alpha$	KCu $\beta$	KCu $\alpha$	KCr $\beta$	KCr $\alpha$
$\lambda$	0.490	0.540	0.560	0.610	1.38	1.54	2.07	2.29
$\mu/2.8$	1.29	1.96	1.82	2.75	23.6	31.9	61.1	81.1

Formula	$\lambda$	0.187	0.207	0.227	0.247	0.272	0.318
Substance*		$\mu_m/(\mu_m)_{H_2O}$ (19, 20)					
N <sub>2</sub> H <sub>4</sub>	Hydrazine	1.76	1.75	1.74	1.70	1.67	1.60
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Methyl formate	3.14	3.14	3.12	3.08	3.06	3.01
C <sub>2</sub> H <sub>4</sub> O	Allyl alcohol	3.16	3.15	3.09	2.98	2.90	2.76
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Propionic acid	3.92	3.90	3.86	3.82	3.76	3.74
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Dimethyl carbonate	4.74	4.73	4.67	4.67	4.61	4.52
C <sub>2</sub> H <sub>4</sub> O	Methyl ethyl ketone	3.87	3.84	3.78	3.71	3.60	3.44
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Ethyl acetate	4.66	4.64	4.60	4.51	4.41	4.25
C <sub>2</sub> H <sub>4</sub>	Benzene	4.04	4.00	3.94	3.84	3.75	3.45
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Paraldehyde	7.04	6.86	6.83	6.70	6.57	6.42
C <sub>7</sub> H <sub>8</sub>	Toluene	4.87	4.83	4.72	4.60	4.40	4.10
C <sub>7</sub> H <sub>8</sub> O	Benzyl alcohol	5.64	5.57	5.52	5.42	5.24	4.95
C <sub>8</sub> H <sub>18</sub>	Octane	6.38	6.29	6.12	6.03	5.76	5.27
C <sub>8</sub> H <sub>18</sub> O	Octyl alcohol	7.17	7.07	6.96	6.84	6.62	6.13

Substance	H <sub>2</sub> † Hydrogen	C <sub>6</sub> H <sub>6</sub> Benzene	C <sub>6</sub> H <sub>12</sub> O Cyclohexanol	C <sub>7</sub> H <sub>8</sub> Toluene	C <sub>7</sub> H <sub>16</sub> Heptane	C <sub>8</sub> H <sub>10</sub> Xylene	C <sub>9</sub> H <sub>12</sub> Mesitylene
$k_m$	0.332	12.88	16.52	15.19	16.52	17.50	19.81
$\lambda$	$\mu/\rho$ (250); cf. (317)						
0.215	0.338						
0.2455	0.333	0.200	0.215	0.204	0.215	0.205	0.203
0.2782	0.531	0.215	0.227	0.214	0.225	0.216	0.210
0.3109	0.420	0.223	0.242	0.225	0.236	0.227	0.219
0.3436	0.449	0.237	0.255	0.238	0.248	0.239	0.232
0.3763	0.465	0.248	0.269	0.250	0.261	0.252	0.244
0.4089	0.385	0.263	0.289	0.265	0.277	0.268	0.261
0.4416	0.517	0.281	0.311	0.284	0.294	0.286	0.280
0.4905	0.459	0.309	0.348	0.312	0.320	0.314	0.309
0.5394	0.412	0.346	0.394	0.348	0.355	0.350	0.346
0.5883	0.333	0.391	0.449	0.393	0.397	0.394	0.391
0.6371	0.349	0.443	0.516	0.444	0.444	0.442	0.443
0.6859	0.489	0.504	0.592	0.504	0.499	0.506	0.502
0.7346	0.445	0.575	0.685	0.573	0.565	0.573	0.571
0.7833	0.450	0.657	0.787	0.650	0.638	0.652	0.650
0.8319	0.454	0.747	0.904	0.740	0.720	0.739	0.737
0.8804	0.637	0.850	1.03	0.840	0.812	0.840	0.831
0.9289	0.325	0.963	1.18	0.950	0.916	0.947	0.943
0.9773	0.457	1.09	1.34	1.07	1.03	1.07	1.07

Gelatin (244)†

V	9.97	7.77	5.87	4.88	4.42	3.93	3.46	3.00	2.50
$\lambda_{min}$	1.24	1.59	2.10	2.53	2.78	3.14	3.56	4.11	4.95
$\mu/\rho$	5.9	12.3	25.8	38.7	56.6	76.2	126	193	312

Celluloid (244)†

V	5.87	4.88	4.42	3.93
$\lambda_{min}$	2.10	2.53	2.78	3.14
$\mu/\rho$	25.6	42.5	60	81

If  $40 < \lambda < 80$ ;  $\mu/\rho = 0.2\lambda^{2.5}$ ; if  $\lambda > 80$ , the increase with  $\lambda$  is less rapid;  $\mu/\rho$  passes through a maximum near  $\lambda = 320 \text{ \AA}$  (193, 194).

\* For  $k$ , see Table 4.

† Values have been deduced (297) from observations (17, 280) on compounds; the probable error is large. Better values are given by the equation  $\mu/\rho = 0.283 + \lambda/6$ ; see section devoted to the elements.

‡ Used "end" radiations of tube with Fe target. Values of  $\mu/\rho$  are too great.

## SCATTERING

For distinction between the two types (modified and unmodified) of scattered radiation, see p. 10. In most cases both types are measured together; from such measurements the coefficient ( $\sigma_s$ ) of absorption due to true scattering can be obtained, but not that ( $\sigma$ ) of total absorption due to scattering. To find that, we must also find either  $\sigma_a$  or both  $\tau$  and  $\mu$  ( $\mu = \tau + \sigma = \tau + \sigma_a + \sigma_s$ ). As both  $\sigma_a$  and  $\tau$  arise from loss of energy on account of the ejection of electrons from their energy-levels, it is exceedingly difficult to obtain either separately. Apparently,  $\sigma$  tends to 0 with  $\lambda$ . For values of  $\lambda$  of order of  $0.01 \text{ \AA}$ , it is assumed that  $\tau = 0$  for elements of low atomic number, and that  $\sigma/\rho$  is proportional to  $Z/A$  for all elements; for  $\lambda$  of order of  $0.1 \text{ \AA}$ ,  $\sigma_s = (1 + \alpha)\sigma/(1 + 2\alpha)$ , approximately, when  $Z$  is small, and practically  $\sigma_s = \sigma$  for other elements. For values of  $\sigma_s/\rho$ , see Table 6. For variation of  $\sigma$  near absorption limits, v. (238).

If ( $\theta$ ) the angle of scattering is small, most of the scattered radiation is of the unmodified type;  $I_m/I_u$  increases with  $\theta$ , but decreases as  $\lambda$  and  $Z$  increase,  $I_m$  and  $I_u$  being, respectively, the intensities of the modified and the unmodified radiation (see Table 7 and Fig. 2).

TABLE 6.—COEFFICIENTS OF MASS-SCATTERING

$\sigma = \sigma_s + \sigma_a$ ;  $\sigma_s/\rho$  is measured directly. In column  $\lambda$ , symbols of form  $\gamma_x$  indicate that filtered (through  $x \text{ cm}$  of Pb)  $\gamma$ -rays from Ra(B + C) were used. In general, filtered X-rays have been used; then  $\lambda$  is the effective wave-length. Unit of  $\lambda = 1 \text{ \AA} = 10^{-8} \text{ cm}$ ; of  $\sigma_s/\rho = 1 \text{ cm}^2/\text{g}$ .



TABLE 6.—(Continued)

	$\lambda_{\text{eff.}}$	$\sigma_s/\rho$	Lit.		$\lambda_{\text{eff.}}$	$\sigma_s/\rho$	Lit.
Al13.....	$\gamma_{1.5}$	0.0450	(198)	Li3.—	0.43	0.165	(243)
	$\gamma_{2.2}$	0.0360	(256)	(Cont'd)	0.54	0.157	(243)
	$\gamma_{2.6}$	0.0323	(247)		0.66	0.169	(243)
	0.082	0.130	(313)		0.71	0.168	(191)
	0.173	0.161	(313)		0.79	0.200	(243)
	0.225	0.147	(313)	Mg12....	$\gamma_{2.2}$	0.035	(198)
	0.373	0.156	(313)	Na23....	0.32	0.173	(243)
	0.458	0.260	(313)		0.43	0.191	(243)
	*	0.29	(120)		0.54	0.248	(243)
B5.....	0.32	0.154	(243)	Pb82....	$\gamma_{1.5}$	0.034	(198)
	0.43	0.162	(243)		$\gamma_{2.2}$	0.030	(256)
	0.54	0.169	(243)	Sn50....	$\gamma_{2.2}$	0.032	(256)
	0.66	0.165	(243)	Zn30....	$\gamma_{2.2}$	0.035	(256)
	0.79	0.179	(243)	H <sub>2</sub> O.....	$\gamma_{2.6}$	0.0383	(247)
C6.....	0.081	0.116†	(5)		0.32	0.198	(243)
	0.32	0.166	(243)		0.43	0.206	(243)
	0.43	0.182	(243)		0.54	0.210	(243)
	0.54	0.194	(243)		0.66	0.216	(243)
	0.66	0.214	(243)		0.79	0.228	(243)
	0.71	0.200	(191)		0.161	0.185	(313)
	0.79	0.234	(243)		0.240	0.206	(313)
Cu29....	*	0.9	(120)		0.285	0.170	(313)
Fe26....	$\gamma_{1.5}$	0.042	(198)		0.501	0.201	(313)
Li3.....	0.32	0.133	(243)	NaCl....	0.41	0.234	(213)

Substance	$\lambda$	$\sigma_s/\rho$	Lit.
C <sub>3</sub> H <sub>8</sub> O <sub>3</sub> Glycerol.....	$\gamma_{2.6}$	0.0406	(247)
C <sub>6</sub> H <sub>6</sub> Benzene.....	0.709	0.238	(191)
C <sub>8</sub> H <sub>18</sub> Octane.....	0.709	0.262	(191)
C <sub>9</sub> H <sub>12</sub> Mesitylene.....	0.709	0.244	(191)
Turpentine.....	$\gamma_{2.6}$	0.0352	(247)
Filter paper.....	*	0.27	(120)

\* Fairly soft X-rays,  $\lambda_{\text{eff.}} = 0.75 \text{ \AA}$  ca.

† From (5), assuming  $\sigma/\rho = \mu/\rho$ , and  $\sigma_s = (1 + \alpha)\sigma/(1 + 2\alpha)$ .

As values of  $\sigma$  given by the equation  $\sigma = \mu - \tau$  ( $\tau$  being obtained by means of an empirical equation) are considered misleading, they are not tabulated here.

TABLE 7.—RATIO OF INTENSITY OF THE MODIFIED ( $I_m$ ) TO THAT OF THE UNMODIFIED ( $I_u$ ) SCATTERED RADIATION

See also (135, 208, 210). \*  $\theta$  = angle of scattering; the atomic number follows the symbol of the scattering substance. If  $\theta$  is small,  $I_u$  is much greater than  $I_m$ .

0.560 $\text{\AA}$ , $\theta = 120^\circ$		0.709 $\text{\AA}$ , $\theta = 90^\circ$	
(1)	$I_m/I_u$	(1)	$I_m/I_u$
(349)		(348)	
Li3.....	$\infty$	Wood.....	2.73
Be4.....	8.72	Paraffin.....	4.69
B5.....	7.02	C6.....	1.45
C6.....	5.48	Al13.....	0.91
Na11.....	3.04	S16.....	0.42
Mg12.....	2.78	(280)	
Al13.....	2.61	C6.....	1.7
Si14.....	2.33	Al13.....	0.7
S16.....	1.91	S16.....	0.29
K19.....	1.72	Cu29.....	0.32
Ca20.....	1.71	Ag47.....	0.21
Cr25.....	0.75	Pb82.....	0.024
Fe26.....	0.51	(280)	
Ni28.....	0.40	0.631 $\text{\AA}$ , $\theta = 90^\circ$	
Cu29.....	0.21	Al13.....	1.0

$\lambda = 0.709 \text{ \AA}$ (MoK $\alpha$ ) (348)					
(1)	Wood	Paraffin	C6	Al13	S16
$\theta$	$I_m/I_u$				
60	1.19	2.29	1.08	0.46	
75	1.85	3.10	1.31	0.74	0.25
90	2.73	4.69	1.45	0.91	0.42
105	3.21	5.16	1.82	1.23	0.67
120	4.57	5.49	2.26	1.45	
135	5.38	6.52	3.42	2.11	
150	6.21	6.98	4.05	2.52	
165	7.00	7.47	4.86		

C6 (280)		$\theta = 120^\circ$		
$\lambda = 0.709 \text{ \AA}$	$\lambda$	C6	Al13	Lit.
$\theta$	$I_m/I_u$	$I_m/I_u$		
30	0.2	0.560	5.48	2.61 (349)
60	0.95	0.709	2.26	1.45 (348)
90	1.7			

\* Davis and Mitchell (*Phys. Rev.*, Sept., 1928) have shown that, for carbon, the scattered radiation considered above as unmodified, contains as well as the truly unmodified radiation, rays of approximate frequency ( $\nu - \nu_c$ ). They found no evidence of scattered rays of greater frequency than that of the primary radiation. Their results have an important bearing on theories giving distribution of scattered radiation. The spectrum of the scattered radiation may depend on the intensity of the primary rays.

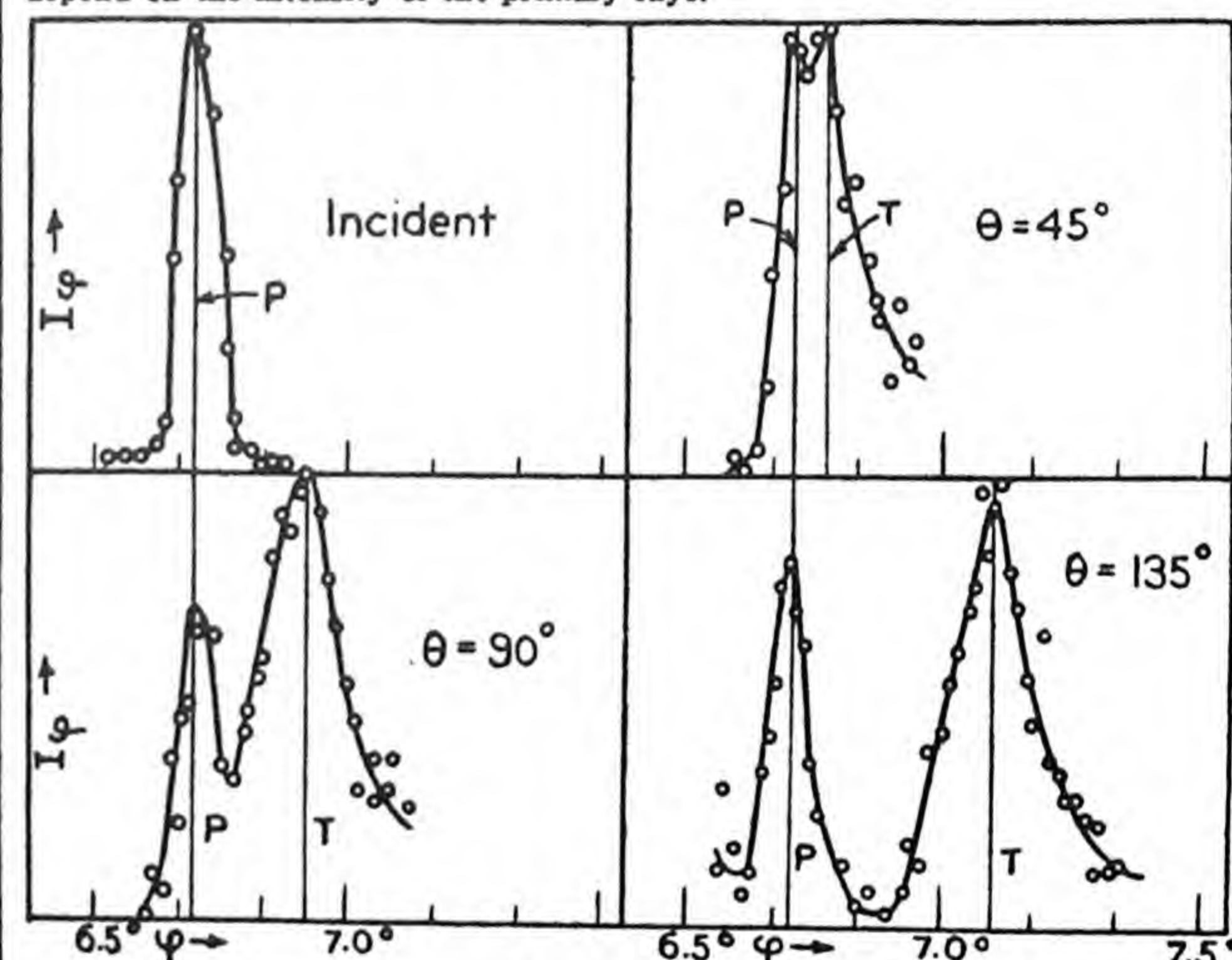


FIG. 2.—Change in wave-length on scattering (97-115). Radiation is MoK $\alpha$  line ( $\lambda = 0.71 \text{ \AA}$ ); scatterer is graphite (C). P = position of primary; T = calculated position of line as modified by scattering;  $\theta$  = angle of scattering;  $I_\phi$  = intensity corresponding to spectrometer angle  $\phi$ .

**Change in Wave-length (Compton Effect).**—All attempts based on the classical theory of radiation to explain the change of  $\lambda$  observed in the case of the modified radiation have been unsuccessful; this theory is, indeed, violated by the fact that the recoil electron is ejected at the same time as the scattered radiation is emitted (43, 54); cf. Fig. 2.

The energy and directions of emission and ejection of these electrons are those required by the quantum theory (114); and by assuming that the conservation principle of energy and of momentum apply to the electron and the quantum, each regarded as a single entity, it is possible to calculate the frequency of the radiation scattered in a given direction ( $\theta$ ) with reference to the primary beam (104, 105, 130). If the electron is free ( $\nu_c = 0$ ) and initially at rest, the conservation equations are

$$h(\nu - \nu_\theta) = m_0 c^2 \left\{ \frac{1}{\sqrt{1 - v^2/c^2}} - 1 \right\}$$



and

$$\left(\frac{h\nu}{c}\right)^2 + \left(\frac{h\nu_\theta}{c}\right)^2 - \frac{2h^2\nu\nu_\theta \cos \theta}{c^2} = \frac{m_0^2 v^2}{1 - v^2/c^2}, \quad \lambda_\theta = \lambda + (0.0486 \sin^2 \theta/2) \text{ \AA},$$

and the energy ( $E_\phi$ ) of a recoil electron ejected in the direction  $\phi$  ( $\leq 90^\circ$ ) is  $E_\phi = \{2h\nu\alpha \cos^2 \phi\} \div \{(1 + \alpha)^2 - \alpha^2 \cos^2 \phi\}$ , where  $\nu$  and  $\lambda$  refer to the incident radiation, and  $\nu_\theta$  and  $\lambda_\theta$  to that scattered at the angle  $\theta$ ,  $v$  is velocity imparted to the electron,  $\tan \phi/2 = -\frac{\tan \theta}{1 + \alpha}$ , and  $\phi$ , like  $\theta$ , is measured from the direction of propagation of the incident beam; see (104). This change in  $\lambda$  is the same as, on the classical theory, would result from the Doppler effect if the initial velocity of the scattering electron were  $c\alpha/(1 + \alpha)$  and lay in the direction of propagation of the incident radiation; and, to a first approximation, it agrees with all the observed values (see Table 8).

Scattering by bound electrons has been similarly treated (108, 208). By taking into account the motion of the electron in its Bohr orbit, and assuming that the reaction between the electron and the impinging quantum is instantaneous, a fair explanation only of the observed facts may be obtained (208); cf. (110). Unless the electron is dislodged from its energy level none of the scattered radiation is of the modified type. The frequency of the modified radiation scattered by electrons of a given energy level (characterized by  $\nu_c$ ) will have a definite maximum ( $\nu - \nu_c$ ); hence the spectrum of the radiation scattered at a given angle should show a series of bands; they have not yet been observed. The short wave-length,  $c/(\nu - \nu_c)$ , corresponding to any level, coincides exactly with that which characterizes the radiation excited by photoelectrons coming from the same level, but, in spite of early evidence to the contrary, it is certain that photoelectrons do not excite an appreciable amount of such tertiary radiation (11, 40, 89-96, 100, 170, 172). For treatment of the Compton effect by the new quantum mechanics, see (140, 164, 222, 299, 332).

TABLE 8.—CHANGE IN WAVE-LENGTH ON SCATTERING (280)

$\delta\lambda_{\text{obs.}} = \lambda_\theta - \lambda$ , where  $\lambda_\theta$  = average wave-length of the modified band scattered at angle  $\theta$ ;  $\delta\lambda_{\text{calc.}} = (0.0486 \sin^2 \theta/2) \text{ \AA}$  is the value calculated on assumption that the scattering electrons are initially free and at rest; atomic number and symbol of scattering substance are in column (1).  $\delta\lambda_{\text{obs.}}$  has been found to equal  $\delta\lambda_{\text{calc.}}$  for  $\lambda$ 's lying between 0.211  $\text{\AA}$  and 0.709  $\text{\AA}$ , and for  $\theta$  between 30 and  $170^\circ$ ; see (11, 42, 72, 73, 75, 76, 105, 106, 107, 111, 115, 126, 170, 275-281, 302, 329, 346); the same is probably true for  $\gamma$ -rays from Ra, but the data are not conclusive, the values of  $\lambda$  and of  $\lambda_\theta$  having been merely inferred from the observed coefficients of absorption in Pb; see (105, 192); cf. Fig. 2. Unit of  $\lambda$  and  $\delta\lambda = 0.001 \text{ \AA} = 10^{-11} \text{ cm}$ .

(1)	$\lambda$	$\theta$	$\delta\lambda_{\text{obs.}}$	$\delta\lambda_{\text{calc.}}$
C6.....	709	30	3 $\pm$ 1	3
C6.....	709	60	12 $\pm$ 0.1	12.1
C6.....	709	90	23.6 $\pm$ 0.3	24.3
Al13.....	709	90	24.4 $\pm$ 0.1	24.3
Al13.....	631	90	24.2 $\pm$ 0.1	24.3
Si16.....	709	90	24.0 $\pm$ 0.5	24.3
Cu29.....	709	90	24.4 $\pm$ 0.2	24.3
Ag47.....	709	90	23.8 $\pm$ 0.2	24.3
Pb82.....	709	90	24.0 $\pm$ 0.2	24.3

Distribution of Scattered Radiation (22-37, 62, 63, 104, 123, 128-130, 162, 319, 320).—Several attempts (cf. Table 9), all based on the assumption that the centers of scattering are the individual electrons external to the nucleus, have been made to derive an

expression for  $I_{\theta\alpha}$  [ $I_{\theta m}$ ,  $I_{\theta i}$ ] in terms of  $\theta$  and  $I$ , the intensity of the unpolarized incident radiation. All obtained are of the form  $I_{\theta\alpha} = \frac{1}{2}IF^2\eta(1 + \cos^2 \theta)$ , where  $\theta$  is the angle of scattering as measured from the direction of propagation of the incident radiation and  $\eta = e^4/m_0^2c^4$ . None of the expressions is entirely satisfactory. It is possible that one may be deduced from wave mechanics. Meanwhile, a qualitative explanation of the facts may be obtained as follows (174, 176, 210, 338).  $U$ -electrons scatter the radiation coherently, so that, if the number of  $U$ -electrons is known, the distribution of the modified radiation can be approximately computed by the method used in obtaining expression 2 (Table 9).  $R$ -electrons do not scatter the radiation coherently, so that, for wave-lengths of the order of 0.7  $\text{\AA}$ ,  $I_{\theta\alpha}$  (v. Table 9) for the unmodified radiation would be equal to  $\frac{1}{2}I\eta R_\theta(1 + \cos^2 \theta)\nu'/\nu$  (v. 1 of Table 9),  $R_\theta$  being the number of  $R$ -electrons involved in scattering the modified radiation through the angle  $\theta$ ,  $\nu'$  the frequency of this radiation, and  $\nu$  that of the primary radiation. The above expression only holds for moderate wave-lengths, as  $I_{\theta}$  diminishes as  $\nu$  increases (see 4, 5 of Table 9, and comments thereon).

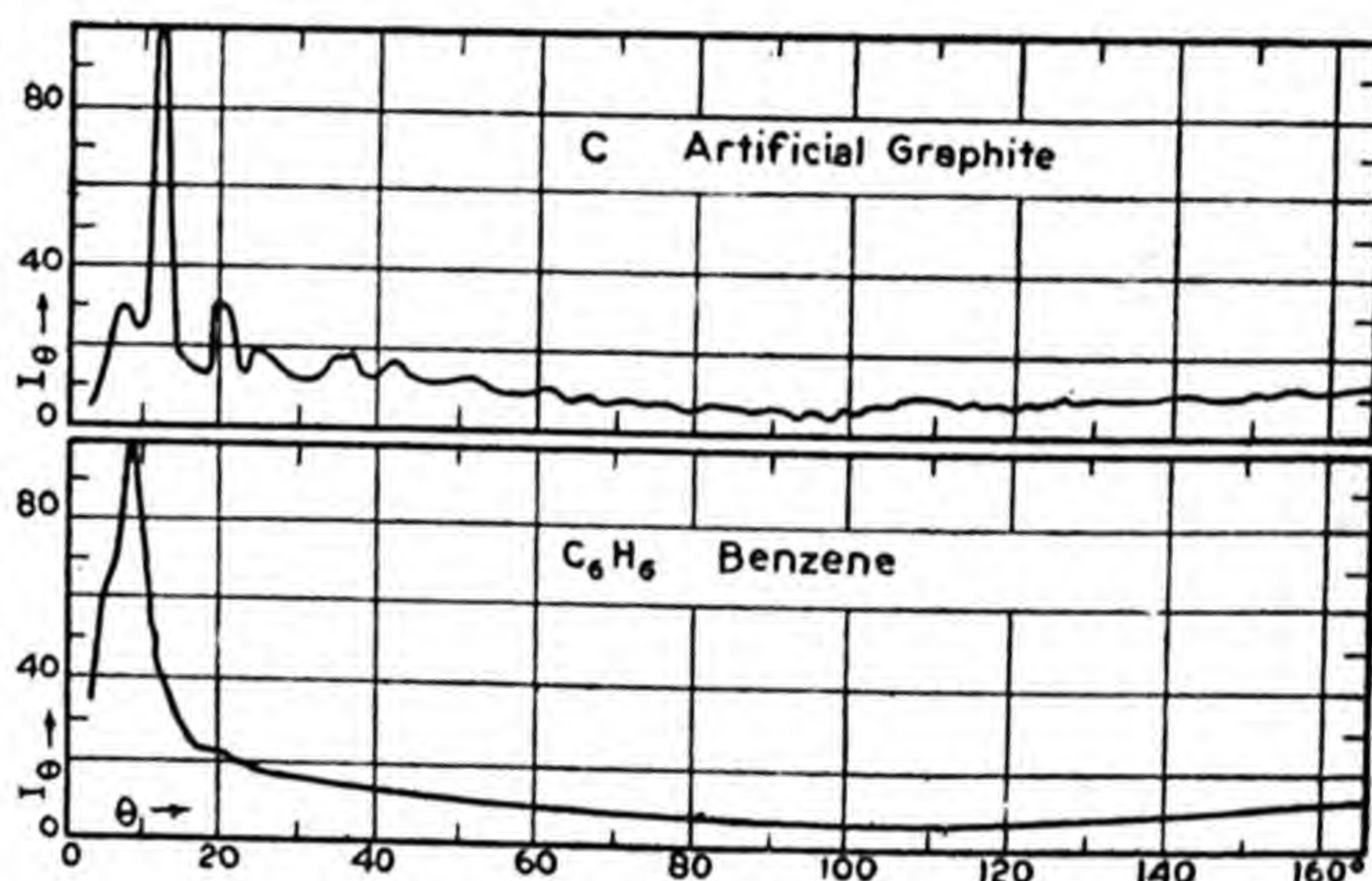


FIG. 3.—Scattering of X-rays by graphite (C) and benzene ( $C_6H_6$ ) (189-191). The  $C_6H_6$ -curve is typical of the scattering by non-crystalline substances, the C-curve of that of crystalline substances. The difference between the two curves arises mainly from the difference in the regularity of the arrangement of the molecules in the two cases. Incident radiation consisted mainly of the  $MoK\alpha$  line ( $\lambda = 0.71 \text{ \AA}$ ).  $I_\theta$  = intensity of radiation scattered at angle  $\theta$ .

All the theoretical expressions for  $F$  make it, and hence  $I_{\theta\alpha}$ , a maximum when  $\theta = 0$ , and, for gases,  $I_{\theta m}$  in the region  $0 \leq \theta < \pi/2$  (cf. (131)) has a single maximum at  $\theta = 0$ , so that the unmodified radiation is scattered coherently by single molecules (176). In solid and pure liquid radiators, in which the atoms are arranged in a more or less orderly manner,  $I_{\theta\alpha}$  apparently = 0 at  $\theta = 0$  and has at least one maximum between  $\theta = 0$  and  $\theta = \pi/2$  (143, 191, 203); cf. (133, 216, 314, 351). See Fig. 3. This results from interference between the radiations scattered by the different atoms or molecules. The value of  $\theta$  at which the maximum occurs is approximately proportional to  $\lambda$ . For some liquids there are 2 maxima (217, 218, 314), and for crystalline solids there may be many (cf. Fig. 3). For theories of scattering by liquids, see (131, 259, 352). Owing to such interference, correct values of  $I_{\theta\alpha}$ ,  $I_{\theta m}$ , or  $I_{\theta i}$  for small values of  $\theta$  cannot easily be derived from experiments on liquids or solids, except in certain cases with crystals, for which such expressions as 3 of Table 9 can be used; but as  $\theta$  increases, the effect of interference appears to decrease. For distribution of radiation diffusely scattered from single crystals, see (203). For effect of temperature, see (61, 128, 200, 204, 357, 358).



TABLE 9.—TYPICAL FORMULAE FOR THE SCATTERING FUNCTION ( $F$ )

If incident radiation is unpolarized,  $I_{\theta\alpha} = \frac{1}{2}I\eta F^2(1 + \cos^2 \theta)$ ;  $\eta = e^4/m_0^2 c^4$ ;  $\alpha = h\nu/m_0 c^2$ ;  $\psi = (4\pi S_{mn}/\lambda) \sin(\theta/2)$ , where  $S_{mn}$  = distance from the  $m$ 'th to the  $n$ 'th electron;  $E$  = total energy reflected at angle  $\theta$  by a thick, ideally imperfect crystal rotating with a velocity of  $\omega$  radians per sec,  $\theta/2$  being the glancing angle at which the incident radiation (energy  $E$ , per sec) is reflected by the crystal,  $\mu$  the effective absorption coefficient,  $N$  = number of scattering units\* per unit of volume, and  $e^{-[B(T) \sin^2 \theta/2]/\lambda^2}$  is the Debye temperature coefficient (128, 357, 358). For other symbols, see p. 8.

Theory	$F^2$	$\sigma_{\alpha\alpha}$	Lit.
1. †Thomson.....	$Z, \sigma_{\alpha\alpha} = 0$ $m=Z, n=Z$	$8\pi Z\eta/3$	(319)
2. ‡Debye-Thomson...	$\sum_{m=1}^Z \sum_{n=1}^Z (\sin \psi)/\psi, \sigma_{\alpha\alpha} = 0$		(129)
3. §Darwin-Compton..	$\frac{4E\omega\mu \sin \theta}{E_1 N^2 \lambda^2 \eta (1 + \cos^2 \theta)} \cdot e^{[B(T) \sin^2 \theta/2]/\lambda^2}$		(356, 123, 124)
4.   Compton.....	$Z \frac{(1 + \cos^2 \theta) + 2\alpha(1 + \alpha)(1 + \cos \theta)^2}{(1 + \cos^2 \theta)(1 + \alpha - \alpha \cos \theta)^2}$	$\frac{8\pi Z\eta(1 + \alpha)}{3(1 + 2\alpha)^2}$	(105)
5.   Breit-Dirac.....	$Z \frac{1}{(1 + \alpha - \alpha \cos \theta)^2}$	$2\pi Z\eta \cdot \frac{1 + \alpha}{\alpha^2} \left\{ \frac{2\alpha(1 + \alpha)}{1 + 2\alpha} - \log_e(1 + 2\alpha) \right\}$	(66, 140)

\* Unit = atom, molecule, etc., see (62).

† Has a very limited application, assumes that electrons scatter independently of each other. In any case, only holds over a moderate range of wave-lengths.

‡ Assumes there are no recoil electrons, that all the scattered radiation is unmodified in  $\lambda$ , and that the electrons have fixed positions relative to the nucleus; cf. (104, 163, 295, 296).

§ Has been used to determine  $F$ , which in this case is called the scattering factor, for atoms and ions in imperfect crystals, but only applies to the unmodified

radiation, see (174, 176, 310, 338). For corresponding formula for perfect crystals, and discussion of problems arising from the fact that in practice crystals are not perfect, see (124); cf. (60, 61, 110).

|| Based on quantum theories. Assumes the natural frequencies of the scattering electrons are small as compared with that of the incident radiation, all the scattered radiation then being of the unmodified type, and therefore incoherent. It requires that  $\sigma = 0$  when  $\lambda = 0$ ; for very small values of  $\lambda$ , it gives too small a value of  $\sigma$ , see (177).

TABLE 10.—OBSERVED DISTRIBUTION OF SCATTERED RADIATION

Incident radiation unpolarized.  $I_{\theta\alpha}$  (or  $I_{\theta m}$  or  $I_{\theta i}$ ) =  $\frac{1}{2}IF^2\eta(1 + \cos^2 \theta)$ ;  $\eta = e^4/m_0 c^4$  cgs units;  $\theta$  = angle of scattering as measured from direction of propagation of incident radiation. Effect of interference (see above) has been ignored, hence values of  $F$  are only approximately correct. Gap = length of spark-gap; unit = 1 cm.

Scattering by atoms or molecules

Values of  $(F_\theta/F_{90})^2$  are given below, cf. (30, 97, 253, 359, 360). Primary rays have not been obtained by reflection from crystals.

Paraffin wax (177),  $\lambda = 0.012 \text{ \AA}$  ca.

$\theta$	33	45	67	90	110	130
$1 + \cos^2 \theta$	1.70	1.50	1.15	1.00	1.12	1.41
$(F_\theta/F_{90})^2$	5.05	3.33	1.65	1.00	0.63	0.43

Filter paper (120), unfiltered X-rays

Gap		1.0	1.5	2.1	3.5	4.0
$\theta$	$1 + \cos^2 \theta$	$(F_\theta/F_{90})^2$				
10	1.97	1.86	1.88	2.15	2.18	2.33
15	1.92	1.69	1.80	1.87	1.69	1.49
20	1.88	1.54	1.60	1.46	1.45	1.22
25	1.81	1.39		1.26	1.29	1.09
30	1.71	1.22	1.22	1.13	1.20	
40	1.59	1.12	1.09	1.05	1.05	0.96

Substance (157)		Li	Na	K	H <sub>2</sub> O	CH <sub>3</sub> OH
$\theta$	$1 + \cos^2 \theta$	$(F_\theta/F_{90})^2, \lambda = 0.19 \text{ \AA}$				
10	1.97	1.10	3.18	3.24	1.50	1.34
20	1.88	0.96	1.79	2.02	0.90	0.85
30	1.75	0.94	1.66	1.54	0.94	0.90
40	1.59	1.01	1.71	1.21	0.92	0.90
50	1.41	1.00	1.18	1.18	0.96	0.98
60	1.25	1.08	1.19	1.19	0.98	0.94
70	1.12		1.03	1.03	1.04	0.99
80	1.03	1.04	1.04	1.04	1.04	
90	1.00	1.00	1.00	1.00	1.00	1.00
100	1.03				1.02	
110	1.12				0.98	
120	1.25	0.96	0.98	0.98	0.96	
130	1.41				0.97	

TABLE 10.—(Continued)

Substance (157)		Li	Na	K	H <sub>2</sub> O	CH <sub>3</sub> OH		
$\theta$	$1 + \cos^2 \theta$	$(F_\theta/F_{90})^2, \lambda = 0.19 \text{ \AA}$						
140	1.59	0.95	0.79	0.79	0.98	0.93		
150	1.75				1.01			
160	1.88	1.02	0.67	0.67	1.02	0.88		
Cu (212); $\lambda = 0.41 \text{ \AA}; F_{90}^2 = 1.49Z = 43.2$								
$\theta$ .....	40	50	60	70	80	90	100	110
$1 + \cos^2 \theta$ ...	1.59	1.41	1.25	1.12	1.03	1.00	1.03	1.12
$(F_\theta/F_{90})^2$ ....	3.26	2.41	1.68	1.60	1.44	1.00	0.97	1.03

Scattering by ions in single crystals

Data are derived from the intensities of reflected rays, and apply to the unmodified radiation only; they require correction for temperature,  $v$ . (61, 128, 200, 354, 355, 357, 358), and may contain small errors due to uncertainties in the values of the extinction coefficients. They indicate that as  $\theta$  approaches zero,  $F$  approaches a value equal to the number of extranuclear electrons associated with the ion; e.g., 10 in the case of  $\text{Na}^+$ . In each case, the number of such electrons is indicated by a subscript; e.g.,  $\text{Na}_{10}^+$ .  $t = 290^\circ\text{C}$ .

NaCl, Rock salt

$\lambda = 0.586 \text{ \AA}$ (61, 62, 63)					$\lambda = 0.709 \text{ \AA}$ (185); cf. (183)			
Ion	$\text{Na}_{10}^+$	$\text{Cl}_{18}^-$	$\text{Na}_{10}^+$	$\text{Cl}_{18}^-$	$\text{Na}_{10}^+$	$\text{Cl}_{18}^-$	$\text{Na}_{10}^+$	$\text{Cl}_{18}^-$
$\theta$	$F$	$F^2$	$F$	$F^2$	$F$	$F^2$	$F$	$F^2$
11.4	8.32	12.72	69.2	161.8				
12.5					9.00	13.6	81.0	185
15	7.61	10.59	57.9	112.1				
20	6.23	8.60	38.8	74.0	7.00	9.45	49.0	89.1
25	4.91	7.44	24.1	55.4				
30	4.01	6.50	16.1	42.2	4.48	6.72	20.1	44.2
35	3.37	5.78	11.4	33.4				
40	2.75	5.15	7.56	26.5	2.70	4.86	7.29	23.6
45	2.22	4.61	4.93	21.2				
50	1.76	4.15	3.10	17.2	1.75	3.56	3.06	12.7
55	1.37	3.70	1.88	13.7				
60	0.76	3.16	0.58	10.0	1.02	2.55	1.04	6.50
70					0.55	1.82	0.30	3.31
80					0.19	1.34	0.04	1.80



TABLE 10.—(Continued)

0.709 Å	NaF (185)		0.709 Å	LiF (185)		0.709 Å	CaF <sub>2</sub> (185); cf. (201)	
Ion	Na <sup>+</sup> <sub>10</sub>	F <sup>-</sup> <sub>10</sub>	Ion	Li <sup>+</sup> <sub>1</sub>	F <sup>-</sup> <sub>10</sub>	Ion	Ca <sup>++</sup> <sub>18</sub>	F <sup>-</sup> <sub>10</sub>
$\theta$	$F$		$\theta$	$F$		$\theta$	$F$	
17.7	7.76	6.44	17.6	1.26	5.89	12.9	15.9	
20	7.25	5.90	20	1.25	5.5	20	12.9	6.00
30	5.13	3.65	30	1.00	3.4	30	9.7	3.35
40	3.47	2.08	40	0.70	2.22	40	7.3	2.25
50	2.22	1.43	50	0.45	1.55	50	5.75	1.58
60	1.40	1.00	60	0.31	1.07	60	4.76	1.23
70	1.10	0.70	70	0.17	0.75	70	3.76	0.93
80	0.82	0.55	80	0.13	0.58	80	3.00	0.70
90	0.55	0.46	90	0.10	0.47	90	2.62	0.52

For Al, see (38); see also (60, 61, 88, 110, 151, 178).

For effect of temperature on intensity of reflection of X-rays from crystals and latest interpretation of results such as those given above, see paper by James, Waller and Hartree, 5, 118: 334; 28.

### RELATIONS BETWEEN ABSORPTION, SCATTERING AND ELECTRON EMISSION

On the quantum theory of absorption and scattering, the intensity of a radiation of frequency  $\nu$  is  $Nh\nu$ , where  $N$  is the number of quanta of energy that pass per unit of time through a unit of area taken normal to the direction of propagation. Hence  $I_s = I_0 e^{-\mu x}$  is equivalent to  $N_s = N_0 e^{-\mu x}$ , and if each scattered quantum were accompanied by a recoil electron, then  $\sigma/\tau$  would equal  $N_R/N_T$ , where  $N_R$  and  $N_T$  are, respectively, the numbers of recoil and of photo-electrons. But some of the scattered radiation (the unmodified) is not accompanied by recoil electrons, hence, in general,  $\sigma/\tau > N_R/N_T$ . These two ratios approach equality as  $\lambda$  and  $Z$  decrease, either separately or conjointly. The values of  $N_R$  and  $N_T$  have been determined only for gases; for values and comparison of  $N_R/N_T$  with  $\sigma/\tau$ , see Table 11.

If  $\nu > \nu_K$ , where  $\nu_K$  is the value of  $\nu_c$  for the  $K$ -level, then more photoelectrons are emitted from the  $K$ -level than from all others (68, 273), and most of the absorption occurs in that level (cf. Fig. 1). In every case the relative numbers of photoelectrons ejected from the several levels depend on the relation of  $\nu$  to the several values of  $\nu_c$ , and none are ejected from those levels for which  $\nu_c > \nu$ ; the absorption varies similarly. As the number of photoelectrons emitted with energy  $h\nu$  is negligible, it is concluded that free electrons produce a negligible amount of photoelectric absorption. More photoelectrons are emitted in the direction of propagation of the incident radiation, than in the opposite direction (7, 134, 340, 341). Theories (14, 15, 78).

TABLE 11.—RELATION BETWEEN ABSORPTION AND THE NUMBER OF EJECTED ELECTRONS

$N_R$  and  $N_T$  = number of recoil electrons and of primary photoelectrons (those having energy =  $h(\nu - \nu_c)$ );  $\sigma$  and  $\tau$  = coefficients of scattering and of photoelectric absorption;  $V$  = tube potential. If all the scattered radiation is of the modified type, then  $N_R/N_T = \sigma/\tau$ . For observations on recoil electrons produced by  $\gamma$ -rays, see (306). Unit of  $\lambda = 1 \text{ Å} = 10^{-8} \text{ cm}$ ; of range = 1 mm; of  $V = 1000 \text{ volt}$ .

Homogeneous X-rays,\* various gases (248); cf. (208)

Gas	$\lambda$	$\sigma/\tau$	$N_R/N_T$		$N_R$	$N_T$
			Obs.	Calc.†		
N <sub>2</sub>	0.614	0.42	0.286	0.340	116	406
O <sub>2</sub>	0.614	0.28	0.194	0.227	119	613
Air	1.54	0.02	0			
Air	0.57	0.41	0.330	0.34	137	418
Air	0.55	1.75	1.58	1.61	153	97

Filtered X-rays, Air (113)

$V$	$\lambda_{eff.}$	$\sigma/\tau$	$N_R/N_T$	$N_R$	$N_T$
21	0.71	0.27	0.10	5	49
34	0.44	0.12	0.9	10	11
52	0.29	3.8	2.7	33	12
74	0.20	10	9	74	8
84	0.17	17	17	68	4
111	0.13	34	72	72	1

\* Rays reflected from a crystal.

† Calculated on assumptions of Jauncey (208)

### APPARENT COEFFICIENT OF ABSORPTION

If the absorbing plate is placed very close to the ionization chamber, radiation scattered from the absorber enters the chamber. The apparent coefficient of absorption ( $\mu'$ ) so obtained is less than the true. All the following data refer to such apparent coefficients. For effect of method of filtration on value of  $\mu'$ , see (177).

TABLE 12.—APPARENT COEFFICIENT OF ABSORPTION OF CERTAIN GROUPS OF  $\gamma$ -RAYS

Absorbing plate is close to ionization chamber.  $\mu'$  = apparent coefficient of absorption; absorbing substance is indicated by subscript. Values of  $(\mu'/\rho)_{Pb}$  are at end of table. Unit of  $\mu'/\rho = 1 \text{ cm}^2/\text{g}$ .

Source	$(\mu'/\rho)_{Al}$	Lit.	Source	$(\mu'/\rho)_{Al}$	Lit.
U-X <sub>1</sub> ...	90, 91	8.9* (262)	Ac-C''...	81	0.073 (292)
		0.26 (262)	Ms-Th <sub>1</sub> ...	89	9.5* (292)
U-X <sub>2</sub> ...		0.052 (262)			0.043 (292)
Io.....	90	400 (82)	Tb-B....	82	59 (292)
		8.35* (82)			11.8* (292)
		0.15 (82)			0.13 (292)
Ra.....	88	130 (284)	Th-C''...	81	0.036 (292)
		6 (284)			
		0.1 (284)			
Ra-B....	82	87 (290)			
		14.7* (290)			
		0.188 (290)			
		0.21 (223)			
Ra-C....	83	0.085 (224)			
		0.047 (224)			
		0.0424 (290)			
Ra-D....	82	16.5* (291)			
		0.36 (291)			
		17.2 (12)			
		0.37 (122)			
Ra-E....	83	16.5 (291)			
		0.36 (291)			
		0.092 (122)			
Ra-F....	84	215 (284)			
Rd-Ac...	90	9.3* (292)			
		0.070 (292)			
Ac-B....	82	44 (292)			
		11.5* (292)			
		0.167 (292)			

\* Very close to value of  $(\mu'/\rho)_{Al}$  for element's  $L$ -radiation.

TABLE 13.—MINIMUM APPARENT COEFFICIENT OF ABSORPTION OF  $\gamma$ -RAYS

Absorbing plates are close to ionization chamber. The radiation being quite heterogeneous, increasing the thickness of the absorbing plate increases the hardness of the transmitted radiation until  $\mu'$  finally reaches a fixed minimum value, cf. (283, 308, 309). It is this minimum that is tabulated. (For variation of  $\mu'$  with filtration, see Table 14.) Unit of  $\rho = 1 \text{ g/cm}^3$ ; of  $\mu' = 1 \text{ cm}^{-1}$ ; of  $\mu'/\rho = 1 \text{ cm}^2/\text{g}$ .

Absorber	$\rho$	$100(\mu'/\rho)_{min}$			
		Th-C''	Ra-C	Ms-Th <sub>1</sub>	U-X <sub>1</sub>
Paraffin*	0.862	3.61	4.64	5.80	5.02
Glass.....	2.52	3.52	4.16	4.48	4.84
Magnesia†	1.92	3.23		4.69	4.78



TABLE 13.—(Continued)

Absorber	$\rho$	$100(\mu'/\rho)_{\min}$			
		Th-C''	Ra-C	Ms-Th <sub>2</sub>	U-X <sub>2</sub>
Slate	2.854	3.37	4.14		4.69
Al, $Z = 13$	2.77	3.24	4.06	4.21	4.69
S, $Z = 16$	1.785	3.69	4.38	4.65	5.16
Fe, $Z = 26$	7.62	3.28	3.99	4.15	4.72
Cu, $Z = 29$	8.81	3.34	3.98	4.23	4.72
Brass	8.35	3.25	3.89	4.25	4.70
Zn, $Z = 30$	7.07	3.30	3.93	4.24	4.65
Sn, $Z = 50$	7.245	3.26	3.88	4.21	4.70
Hg, $Z = 80$	13.59		4.72§		6.12
Pb, $Z = 82$	11.4		4.34	5.44	6.36

\* Paraffin wax, values of  $\mu'_{\min}$  are high on account of presence of H.

† Magnesia brick.

‡ Values of  $\mu'_{\min}$  are probably too high.

§ Valid for thickness between 1 and 25 cm (283).

|| Valid for thickness between 2 and 22 cm (309); cf. (208, 221).

TABLE 14.—APPARENT COEFFICIENT OF ABSORPTION OF FILTERED  $\gamma$ -RAYS

Rays from Ra(B and C). Unless the filtering is such that, for a thin plate of the absorber,  $\mu' = \mu'_{\min}$  of the absorber (v. Table 13), an additional filtering through the absorber will cause  $\mu'$  to approach  $\mu'_{\min}$ . In general, the filtered rays are softened by transmission through a substance of lower atomic weight than the filter, and are hardened in the reverse case (167). For the following data the filter consisted of two plates: A "hardener"  $H$  of thickness  $f_h$ , and a plate of the absorber of thickness  $f_a$ . After passing through these plates in the order named, the apparent absorption ( $\mu'$ ) of the rays by a second plate of the absorber, thickness  $x$ , is measured. The three plates are stacked close together and the plate of thickness  $x$  is in contact with the ionization chamber. Observed values of  $\mu'/\rho$  may be compared with those of Table 13. Unit of  $f_a$ ,  $f_h$ , and  $x = 1$  cm; of  $\mu'/\rho = 1$  cm<sup>2</sup>/g.

Absorber = Al (249),  $x = 3.2$  cm

$f_a =$		0.2	3.4	6.6	9.8	13
$H$	$f_h$	$100\mu'/\rho$				
	0	9.57	4.27	4.23	4.24	4.23
Cu	2.4	3.58	3.85	4.02	4.03	4.04
Sn	2.5	3.18	3.51	3.71	3.83	3.81
Pb	0.2	3.54	3.75	3.85	3.96	3.99
Pb	1.1	2.92	3.21	3.41	3.61	3.64
Pb	2.0	2.77	3.15	3.23	3.41	3.48
Pb	2.9	2.67	3.01	3.22	3.30	3.38
Pb	3.8	2.52	2.92	3.15	3.27	3.35

Absorber = Fe (249)

$x =$		0.8	1	2	2	2	2	2
$f_a =$		0.2	1	2	4	6	8	10
$H$	$f_h$	$100\mu'/\rho$						
	0	4.53(?)	4.28	4.20	4.13	4.02	3.95	
Al	7.5	4.58	4.21	4.08	4.02	3.97	3.94	
Cu	2.4	4.16	4.11	4.02	4.01	3.93	3.92	
Sn	2.5	3.56	3.84	3.86	3.90	3.89	3.89	
Pb	0.2	3.83	3.96	3.98	3.97	3.96	3.92	
Pb	1.1	2.91	3.37	3.53	3.67	3.76	3.78	3.83
Pb	2.0	2.79	3.15	3.39	3.57	3.70	3.72	3.76
Pb	2.9	2.75	3.07	3.32	3.51	3.64	3.68	3.70
Pb	3.8	2.71	3.04	3.29	3.50	3.61	3.67	3.70

Absorber—miscellaneous (81, 82)  
Hardener = Pb;  $f_a = 0$ ;  $x$  is not stated

$f_h =$	0.3	1.0	$f_h =$	0.3	1.0
Material	$100\mu'/\rho$		Material	$100\mu'/\rho$	
Air (gas)	4.8		CO <sub>2</sub>	5.1	4.70
Air (liquid)	4.84	4.60	H <sub>2</sub> O (liquid)	5.58	4.72
H	4.7*		Wood	5.21	4.29

\* Apparently too small; cf. (1).

## LITERATURE

(For a key to the periodicals see end of volume)

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- (240) Martin, 5, 115: 420; 27. (241) Meitner, 96, 22: 334; 24. (242) Meitner and Hahn, 63, 14: 873; 13. (243) Mertz, 2, 28: 891; 26. (244) Miller, 2, 8: 309; 16. (245) Morehouse, 2, 27: 794; 26. (246) Moseley and Makower, 3, 23: 302; 12. (247) Neukirchen, 96, 6: 106; 21. (248) Nuttall and Williams, 3, 1: 1217; 26. (249) Oba, 3, 27: 601; 14.
- (250) Olson, Dershem and Storch, 2, 21: 30; 23. (251) Oppenheimer, 96, 41: 268; 27. (252) Owen, 201, 16: 161; 11. (253) Owen, 5, 86: 426; 12. (254) Owen, 5, 94: 339; 18. (255) Owen, 5, 94: 510; 18. (256) Owen, Fleming and Fage, 67, 36: 355; 21. (257) Pealing, 3, 24: 765; 12. (258) Plimpton, 3, 42: 302; 21. (259) Raman and Ramanathan, 512, 8: 127; 23.
- (260) Rawlinson, 3, 28: 274; 14. (261) Read, 2, 28: 898; 26. (262) Richardson, 3, 27: 252; 14. (263) Richardson, 5, 91: 396; 15. (264) Richtmyer, 2, 17: 264; 21. (265) Richtmyer, 4, 17: 433; 21. (266) Richtmyer, 2, 18: 13; 21. (267) Richtmyer, 2, 19: 418; 22. (268) Richtmyer, 2, 26: 724; 25. (269) Richtmyer, 2, 27: 1; 26.
- (270) Richtmyer and Grant, 2, 15: 547; 20. (271) Richtmyer and Spencer, 2, 23: 550; 24. (272) Richtmyer and Warburton, 2, 22: 539; 23. (273) Robinson, 6, 104: 455; 23. (274) Ross, 2, 22: 279; 23. (275) Ross, 2, 22: 524; 23. (276) Ross, 197, 9: 246; 23. (277) Ross, 197, 10: 304; 24. (278) Ross, 2, 26: 282; 25. (279) Ross, 197, 11: 567; 25.
- (280) Ross, 197, 11: 569; 25. (281) Ross and Webster, 197, 11: 56; 25. (282) Ross and Webster, 197, 11: 56; 25. (283) Russell, 5, 88: 75; 13. (284) Russell and Chadwick, 3, 27: 112; 14. (285) Russell and Soddy, 3, 21: 130; 11. (286) Rutherford, 3, 34: 153; 17. (287) Rutherford and Andrade, 3, 27: 854; 14. (288) Rutherford and Barnes, 3, 28: 263; 14. (289) Rutherford and Andrade, 3, 30: 361; 15.
- (290) Rutherford and Richardson, 3, 25: 722; 13. (291) Rutherford and Richardson, 3, 26: 324; 13. (292) Rutherford and Richardson, 3, 26: 937; 13. (293) Sadler, 3, 18: 107; 09. (294) Sadler and Mesham, 3, 24: 138; 12. (295) Schott, 5, 96: 395; 20. (296) Schott, 5, 104: 153; 23. (297) Schott, 2, 23: 119; 24. (298) Schottky, 63, 17: 581; 16. (299) Schrödinger, 8, 82: 257; 27.
- (300) Seitz, 63, 7: 689; 06. (301) Seitz, 63, 13: 476; 12. (302) Sharp, 2, 26: 691; 26. (303) Siegbahn, 63, 15: 753; 14. (304) Siegbahn, 678. (305) Simons, 3, 41: 120; 21. (306) Skobelzyn, 96, 24: 393; 24. 28: 278; 24. 43: 354; 27. (307) Smekal, 63, 27: 831; 26. (308) Soddy and Russell, 3, 16: 620; 09. (309) Soddy, Soddy and Russell, 3, 19: 725; 10.
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- (330) Welo, 51, 4: 71; 23. (331) Wentzel, 96, 38: 518; 26. (332) Wentzel, 96, 43: 1, 779; 27. (333) Whiddington, 201, 15: 574; 10. (334) Whiddington, 5, 85: 99; 11. (335) Whiddington, 201, 16: 150; 11. (336) Whiddington, 3, 43: 1116; 22. (337) Williams, 5, 94: 567; 18. (338) Williams, 3, 2: 657; 26. (339) Wilson, 3, 21: 532; 11.
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- (350) Wyckoff, 12, 5: 277; 23. (351) Wyckoff, 12, 5: 455; 23. (352) Zernike and Prins, 96, 41: 184; 27. (353) Ahmad, 5, 109: 206; 25. (354) Backhurst, 5, 102: 340; 22. (355) Bragg, 62, 215: 264; 15. (356) Compton, 2, 9: 29; 17. 10: 95; 17. (357) Debye, 8, 43: 49; 14. (358) Waller, *Diss.*, Upsala, 1925. (359) Klein and Nishiwa, 58, 122: 398; 28.
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EMISSION OF X-RAYS, WAVE-LENGTHS AND DATA ON ABSORPTION LIMITS<sup>1,2</sup>

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CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Units and constants.	Unités et constantes.	Einheiten und Konstanten.	Unità e costanti.....	23
Notation.	Notation.	Bezeichnungen.	Notazione.	
General.	Généralités.	Allgemeines.	Considerazioni generali..	24
Normal energy-levels, series, and subseries.	Niveaux d'énergie normaux, séries et subséries.	Normale Energieniveaux, Serien und Subserien.	Livelli di energia normali, serie e sottoserie.	25
Quantum notation.	Notation quantique.	Quantenbezeichnungen.	Notazione quantistica..	25
Normal lines: notation, intensities and width.	Raies normales: notation, intensités et largeur.	Normallinien: Bezeichnungen, Intensitäten und Weiten.	Linee normali: notazione, intensità e larghezza..	25
Non-diagram lines.	Raies ne figurant pas dans les diagrammes.	Nichtdiagram-Linien.	Linee non comprese nel diagramma.....	26
Origin of X-rays.	Origine des rayons X.	Ursprung der Röntgenstrahlen.	Origine dei raggi X.....	27
Planck's constant.	Constante de Planck.	Planck-Konstante.	La costante di Planck.....	
Line spectra.	Spectres de raies.	Linien-Spektra.	Spettri di linee.	27
General characteristics.	Caractéristiques générales.	Allgemeine Charakteristik.	Caratteristiche generali.	27
Variation of frequency with atomic number.	Variation de la fréquence avec le nombre atomique.	Frequenzänderung mit der Atomzahl.	Variazione della frequenza con il numero atomico.....	27
Regular doublets.	Doublets réguliers.	Regelmässige Dubletts.	Doppietti regolari.....	28
Irregular doublets.	Doublets irréguliers.	Unregelmässige Dubletts.	Doppietti irregolari.....	29
Selection principles.	Principes de sélection.	Trennungs Prinzipien.	Principi selettivi.....	31
Intensities of lines.	Intensités des raies.	Linien Intensitäten.	Intensità delle linee....	31
Variation with energy-level.	Variation avec le niveau d'énergie.	Änderung mit dem Energieniveau.	Variazione con il livello di energia.....	31
Relative intensities within a subseries.	Intensités relatives dans une subsérie.	Relative Intensitäten innerhalb der Subserien.	Intensità relativa in una sottoserie.....	32
Variation with tube voltage.	Variation avec le voltage du tube.	Änderung mit der Röhrenspannung.	Variazione col voltaggio del tubo.....	32
Ratio to continuous spectrum.	Rapport au spectre continu.	Verhältnis zum kontinuierlichen Spektrum.	Rapporto con lo spettro continuo.....	32
Primary standards of wavelength.	Étalons primaires de longueur d'onde.	Wellenlängen Standards.	Campioni primari di lunghezza d'onda.....	33
Limiting frequencies of series.	Fréquences limites des séries.	Frequenz der Endserien.	Frequenze limiti delle serie.....	35
Characteristic emission spectra and absorption limits.	Spectres d'émission caractéristiques et limites d'absorption.	Charakteristische Emissionsspektren und Absorptionsgrenzen.	Emissione di spettri caratteristici e limiti di assorbimento.....	36
Absorption limits: fine structure and effect of chemical combination.	Limites d'absorption: structure fine et effet de la combinaison chimique.	Absorptionsgrenzen: Feinstruktur und der Einfluss chemischer Bindung.	Limiti di assorbimento, strutture fini ed effetto delle combinazioni chimiche.....	44
Continuous spectra.	Spectres continus.	Kontinuierliche Spektra.	Spettri continui.....	45

## UNITS AND CONSTANTS

All quantities are expressed in  $\mu$ gse (cgs electrostatic) units unless others are indicated. Wave-lengths are expressed in Ångstrom units (Å), or in mÅ ( $1\text{ mÅ} = 0.001\text{ Å} = 1\text{XU} = 10^{-11}\text{ cm}$ ), electrical potential in absolute volts ( $1\text{ abs. volt} = 10^8\text{ cgs unit} = 3.3349 \times 10^{-3}\text{ cgs unit} = 0.99958\text{ Int. volt (v)*}$ ) and in absolute kilo-volts (kv).

For the Rydberg constant ( $N_\infty$ ) and the Rydberg frequency ( $\nu_\infty$ ) the following values, differing from the "derived" values given in Vol. I, p. 18, but agreeing with experimental determinations, are

\* As defined by the equation, Weston normal cell at  $20^\circ\text{C} = 1.018300\text{ Int. volt}$ .

<sup>1</sup> Data up to June, 1925, were collected by Webster and Nicholas, all data on the fine structure of absorption limits and the effects of chemical combination being collected by Nicholas and all other data by Webster. Owing to unavoidable delay in publication, it became desirable to add new data and to revise certain of the old so as to bring the report up to date. This was done for line spectra in December, 1927, by Siegbahn and for continuous spectra in May, 1928, by Nicholas.

<sup>2</sup> For data concerning the "J-phenomenon" and the polarization of X-rays, see p. 1 and p. 2.

## UNITÉS ET CONSTANTES

Toutes les unités sont exprimées en unités  $\mu$ gse (cgs électrostatique) à moins d'une autre indication. Les longueurs d'onde sont exprimées en unités d'Ångstrom (Å), ou en mÅ ( $1\text{ mÅ} = 0.001\text{ Å} = 1\text{XU} = 10^{-11}\text{ cm}$ ), le potentiel électrique en volts absolus ( $1\text{ volte abs.} = 10^8\text{ unités cgs} = 3.3349 \times 10^{-3}\text{ unités cgs} = 0.99958\text{ volte Int. (v)*}$ ) et en kilo-voltes absolus (kv).

Pour la constante de Rydberg ( $N_\infty$ ) et la fréquence de Rydberg ( $\nu_\infty$ ) les valeurs suivantes, différant des valeurs "dérivées" données dans le Vol. I, p. 18, mais en accord avec les déterminations

\* Tel qu'il est défini par l'équation, pile Weston normale à  $20^\circ\text{C} = 1.018300\text{ volt Int.}$



used:  $N_{\infty} = 109\,737\text{ cm}^{-1}$ ,  $\nu_{\infty} = 3.29057 \times 10^{15}\text{ sec}^{-1}$ . Siegbahn's value ( $d_c = 3.02904\text{ \AA}$ ) for the grating space of calcite in first order is used.

### NOTATION

**General.**—Except as otherwise defined, symbols are to be interpreted as defined in Vol. I, p. 16.

- $i$  Cathode ray current reaching the target.
- $I_{\psi}$  Apparent intensity: the value of ionization current obtained by complete absorption of  $J_{\psi}$  in the gas in the ionization chamber.
- $J_{\psi}$  Intensity (energy) of radiation in direction  $\psi$  with reference to cathode rays.
- $j, k, n$  Quantum numbers (v. p. 25).
- $N_{\infty}$  Rydberg's constant, commonly denoted by  $R$ .
- $S, s$  Screening numbers (v. p. 29).
- $V$  Electrical potential.
- $V_0$  Excitation potential.
- $V_T$  Tube potential: The effective accelerating potential acting upon the cathode rays.
- $\Delta$  Difference, e.g.,  $\Delta\lambda$  = difference in wave-length.
- $\psi$  Angle the direction of propagation of the observed beam of X-rays makes with the direction of propagation of the exciting cathode stream (see Fig. 19).
- $\nu$  Frequency, not reciprocal of wave-length.
- $\nu_0$  High frequency limit.
- $\nu_{\infty}$  Rydberg's fundamental frequency.
- $d\omega$  Elementary solid angle.

### EINHEITEN UND KONSTANTE

Alle Grössen sind im cgse (cgs elektrostatisch)-Einheiten ausgedrückt, ausser es ist etwas anderes angegeben. Es sind ausgedrückt, Wellenlängen in Ångström Einheiten (Å) oder in mÅ (1 mÅ = 0,001 Å =  $10^{-11}$  cm), das elektrische Potential in absoluten Volt (1 abs. Volt =  $10^9$  cgs Einheit =  $3,3349 \times 10^{-3}$  cgse Einheit = 0,99958 Int. Volt (v)\*) und in absoluten Kilovolt (kv).

Für die Rydberg-Konstante ( $N_{\infty}$ ) und die Rydberg-Frequenz ( $\nu_{\infty}$ ) werden Werte gebraucht, die von den "abgeleiteten" Werten abweichen, welche im Band I, S. 18 angegeben sind, aber mit den experimentellen Daten übereinstimmen, und zwar ist  $N_{\infty} = 109\,737\text{ cm}^{-1}$ ,  $\nu_{\infty} = 3,29057 \times 10^{15}\text{ sec}^{-1}$ . Es wird der Wert von Siegbahn für die Gitterkonstante erster Ordnung des Kalzits ( $d_c = 3,02904\text{ \AA}$ ) verwendet.

### BEZEICHNUNGEN

**Allgemeines.**—Wenn nicht anders angegeben, die Symbole entsprechen den, welche im Bd. I, S. 16 festgelegt sind.

- $i$  Auftreffender Kathodenstrahlenstrom.
- $I_{\psi}$  Scheinbarer Intensität: der Wert des Ionisationsstromes der durch eine vollständige Absorption von  $J_{\psi}$  im Gase der Ionisationskammer erhalten wird.
- $J_{\psi}$  Intensität (Energie) der Strahlung in der Richtung  $\psi$  mit Bezug auf die Kathodenstrahlen.
- $j, k, n$  Quantenzahlen (v. S. 25).
- $N_{\infty}$  Rydberg-Konstante, meistens mit  $R$  bezeichnet.
- $S, s$  Abschirmungszahlen (v. S. 29).
- $V$  Elektrisches Potential.
- $V_0$  Anregungspotential.
- $V_T$  Röhrenpotential: das effektiv beschleunigende Potential, wirkend auf die Kathodenstrahlen.
- $\Delta$  Differenz, d. i.,  $\Delta\lambda$  = Differenz in Wellenlänge.
- $\psi$  Winkel den die beobachteten Röntgenstrahlen mit der Fortpflanzungsrichtung des erregenden Kathodenstrahlenbündels bildet (siehe Fig. 19).

\* Definiert durch die Gleichung, Weston-Normalelement bei  $20^{\circ}\text{C} = 1,018300\text{ Int. Volt.}$

expérimentales, ont été utilisées:  $N_{\infty} = 109\,737\text{ cm}^{-1}$ ,  $\nu_{\infty} = 3,29057 \times 10^{15}\text{ sec}^{-1}$ . La valeur de Siegbahn ( $d_c = 3,02904\text{ \AA}$ ) pour la constante du réseau de la calcite est utilisée en premier lieu.

### NOTATION

**Généralités.**—À moins d'une autre indication, les symboles doivent être interprétés comme définis dans Vol. I, p. 16.

- $i$  Courant de rayons cathodiques atteignant l'anticathode.
- $I_{\psi}$  Intensité apparente: la valeur du courant d'ionisation obtenu par l'absorption complète de  $J_{\psi}$  par le gaz dans la chambre d'ionisation.
- $J_{\psi}$  Intensité (énergie) de la radiation dans la direction  $\psi$  par rapport aux rayons cathodiques.
- $j, k, n$  Nombres quantiques (v. p. 25).
- $N_{\infty}$  Constante de Rydberg, communément désignée par  $R$ .
- $S, s$  Constante de réduction (v. p. 29).
- $V$  Potentiel électrique.
- $V_0$  Potentiel d'excitation.
- $V_T$  Potentiel du tube: le potentiel accélérateur effectif, agissant sur les rayons cathodiques.
- $\Delta$  Différence, e.g.,  $\Delta\lambda$  = différence dans la longueur d'onde.
- $\psi$  Angle que fait la direction de propagation du faisceau de rayons X observés avec la direction de propagation du courant cathodique d'excitation (voir Fig. 19).
- $\nu$  Fréquence, non réciproque de longueur d'onde.
- $\nu_0$  Limite de haute fréquence.
- $\nu_{\infty}$  Fréquence fondamentale de Rydberg.
- $d\omega$  Angle solide élémentaire.

### UNITÀ E COSTANTI

Tutte le quantità sono espresse in unità cgse (cgs elettrostatico) a meno che non venga altrimenti indicato. Le lunghezze d'onda sono date in unità Ångström (Å) o in mÅ (1 mÅ = 0,001 Å =  $10^{-11}$  cm), il potenziale elettrico in volte assoluti (1 ass. volta =  $10^9$  unità cgs =  $3,3349 \times 10^{-3}$  unità cgse = 0,99958 Int. volte (v)\*) e in kilo-volte assoluti (kv).

Per la costante di Rydberg ( $N_{\infty}$ ) e per la frequenza di Rydberg ( $\nu_{\infty}$ ) s'impiegano i valori seguenti che differiscono dai valori "derivati" (che sono dati nel Vol. I, p. 18) ma sono d'accordo con le determinazioni sperimentali:  $N_{\infty} = 109\,737\text{ cm}^{-1}$ ,  $\nu_{\infty} = 3,29057 \times 10^{15}\text{ sec}^{-1}$ . Per la distanza reticolare della calcite in primo ordine è usato il valore di Siegbahn ( $d_c = 3,02904\text{ \AA}$ ).

### NOTAZIONE

**Generalità.**—Eccetto che venga altrimenti indicato i simboli devono venire interpretati secondo le definizioni indicate nel Vol. I, p. 16.

- $i$  Corrente di raggi catodici che raggiungono il bersaglio.
- $I_{\psi}$  Intensità apparente: valore della corrente di ionizzazione ottenuta per mezzo dell'assorbimento completo di  $J_{\psi}$  del gas nella camera di ionizzazione.
- $J_{\psi}$  Intensità (energia) della radiazione nella direzione  $\psi$  rispetto ai raggi catodici.
- $j, k, n$  Numeri quantici (v. p. 25).
- $N_{\infty}$  Costante di Rydberg comunemente denotata con  $R$ .
- $S, s$  Numeri di schermo (v. p. 29).
- $V$  Potenziale elettrico.
- $V_0$  Potenziale di eccitazione.
- $V_T$  Potenziale del tubo: il potenziale di accelerazione effettivo che agisce sopra i raggi catodici.
- $\Delta$  Differenza, per es.,  $\Delta\lambda$  = differenza in lunghezza d'onda.
- $\psi$  Angolo che la direzione di propagazione del fascio di raggi X osservato fa con la direzione di propagazione del fascio dei raggi catodici eccitanti (vedi Fig. 19).

\* Come definito dall'equazione, una pila normale Weston a  $20^{\circ}\text{C} = 1,018300\text{ volt Int.}$



$\nu$  Frequenz, nicht der reziproke Wert der Wellenlänge.  
 $\nu_0$  Hochfrequenzgrenze.  
 $\nu_\infty$  Rydberg's fundamentale Frequenz.  
 $d\omega$  Elementarer fester Winkel.

$\nu$  Frequenza, non il valore reciproco della lunghezza d'onda.  
 $\nu_0$  Limite di alta frequenza.  
 $\nu_\infty$  Frequenza fondamentale di Rydberg.  
 $d\omega$  Angolo solido elementare.

TABLE 1.—NOTATION FOR NORMAL ENERGY-LEVELS, SERIES, AND SUBSERIES

Siegbahn* (142) 1918	M. de Broglie* (19) 1922	L. de Broglie and Dauvillier* (20) 1922	Bohr and Cos- ter† (17) 1923	Bohr and Cos- ter† (17) 1923	Sommerfeld§ (149) 1924	Russell and Saunders	Siegbahn* (142) 1918	M. de Broglie* (19) 1922	L. de Broglie and Dauvillier* (20) 1922	Bohr and Cos- ter† (17) 1923	Bohr and Cos- ter† (17) 1923	Sommerfeld§ (149) 1924	Russell and Saunders
K	K	K	K	1(1, 1)	K	H¶ 1 <sup>2</sup> S <sub>1</sub>		N <sub>3</sub>	N <sub>6</sub>				
L <sub>1</sub>	L <sub>1</sub>	L <sub>1</sub>	L <sub>I</sub>	2(1, 1)	L <sub>11</sub>	Li 2 <sup>2</sup> S <sub>1</sub>		N <sub>3</sub>	N <sub>4</sub>				
L <sub>2</sub>	L <sub>2</sub>	L <sub>2</sub>	L <sub>II</sub>	2(2, 1)	L <sub>21</sub>	Li 2 <sup>2</sup> P <sub>1</sub>	N <sub>2</sub>	N <sub>2</sub>	N <sub>3</sub>	N <sub>VI</sub>	4(4, 3)	N <sub>43</sub>	K 4 <sup>2</sup> F <sub>3</sub>
L <sub>3</sub>	L <sub>1</sub>	L <sub>1</sub>	L <sub>III</sub>	2(2, 2)	L <sub>22</sub>	Li 2 <sup>2</sup> P <sub>2</sub>	N <sub>1</sub>	N <sub>1</sub>	N <sub>2</sub>	N <sub>VII</sub>	4(4, 4)	N <sub>44</sub>	K 4 <sup>2</sup> F <sub>4</sub>
									N <sub>1</sub>				
M <sub>3</sub>	M <sub>3</sub>	M <sub>3</sub>	M <sub>I</sub>	3(1, 1)	M <sub>11</sub>	Na 3 <sup>2</sup> S <sub>1</sub>		O <sub>5</sub>	O <sub>6</sub>				
M <sub>4</sub>	M <sub>4</sub>	M <sub>3</sub>	M <sub>II</sub>	3(2, 1)	M <sub>21</sub>	Na 3 <sup>2</sup> P <sub>1</sub>	O <sub>5</sub>	O <sub>5</sub>	O <sub>6</sub>	O <sub>I</sub>	5(1, 1)	O <sub>11</sub>	Rb 5 <sup>2</sup> S <sub>1</sub>
M <sub>2</sub>	M <sub>3</sub>	M <sub>4</sub>	M <sub>III</sub>	3(2, 2)	M <sub>22</sub>	Na 3 <sup>2</sup> P <sub>2</sub>	O <sub>4</sub>	O <sub>4</sub>	O <sub>5</sub>	O <sub>II</sub>	5(2, 1)	O <sub>21</sub>	Rb 5 <sup>2</sup> P <sub>1</sub>
M <sub>2</sub>	M <sub>2</sub>	M <sub>3</sub>	M <sub>IV</sub>	3(3, 2)	M <sub>32</sub>	Na 3 <sup>2</sup> D <sub>2</sub>	O <sub>3</sub>	O <sub>3</sub>	O <sub>4</sub>	O <sub>III</sub>	5(2, 2)	O <sub>22</sub>	Rb 5 <sup>2</sup> P <sub>2</sub>
M <sub>1</sub>	M <sub>1</sub>	M <sub>2</sub> (?)	M <sub>V</sub>	3(3, 3)	M <sub>33</sub>	Na 3 <sup>2</sup> D <sub>3</sub>	O <sub>2</sub>	O <sub>2</sub>	O <sub>3</sub>	O <sub>IV</sub>	5(3, 2)	O <sub>32</sub>	Rb 5 <sup>2</sup> D <sub>2</sub>
	M <sub>1</sub>	M <sub>1</sub>					O <sub>1</sub>	O <sub>1</sub>	O <sub>2</sub>	O <sub>V</sub>	5(3, 3)	O <sub>33</sub>	Rb 5 <sup>2</sup> D <sub>3</sub>
									O <sub>1</sub>				
N <sub>7</sub>	N <sub>8</sub>	N <sub>10</sub>	N <sub>I</sub>	4(1, 1)	N <sub>11</sub>	K 4 <sup>2</sup> S <sub>1</sub>		P <sub>3</sub>	P <sub>3</sub>	P <sub>I</sub>	6(1, 1)	P <sub>11</sub>	Cs 6 <sup>2</sup> S <sub>1</sub>
N <sub>6</sub>	N <sub>7</sub>	N <sub>9</sub>	N <sub>II</sub>	4(2, 1)	N <sub>21</sub>	K 4 <sup>2</sup> P <sub>1</sub>	P <sub>3</sub>	P <sub>3</sub>	P <sub>2</sub>	P <sub>II</sub>	6(2, 1)	P <sub>21</sub>	Cs 6 <sup>2</sup> P <sub>1</sub>
N <sub>5</sub>	N <sub>6</sub>	N <sub>8</sub>	N <sub>III</sub>	4(2, 2)	N <sub>22</sub>	K 4 <sup>2</sup> P <sub>2</sub>	P <sub>2</sub>	P <sub>2</sub>	P <sub>2</sub>	P <sub>III</sub>	6(2, 2)	P <sub>22</sub>	Cs 6 <sup>2</sup> P <sub>2</sub>
N <sub>4</sub>	N <sub>5</sub>	N <sub>7</sub>	N <sub>IV</sub>	4(3, 2)	N <sub>32</sub>	K 4 <sup>2</sup> D <sub>2</sub>	P <sub>1</sub>	P <sub>1</sub>	P <sub>1</sub>				
N <sub>3</sub>	N <sub>4</sub>	N <sub>6</sub>	N <sub>V</sub>	4(3, 3)	N <sub>33</sub>	K 4 <sup>2</sup> D <sub>3</sub>							
							Q	Q	Q	Q	7(1, 1)	Q <sub>11</sub>	87 7 <sup>2</sup> S <sub>1</sub>

\* Subscripts are in inverse order of intensity of emission or absorption and in direct order of frequency of vibration; 1 denotes the subseries of most intense emission, which is the one of lowest frequency.

† This is known as the Bohr and Coster letter system. Subscripts denote the order in which the energy levels characteristic of the series are filled in a sequence of atoms proceeding in order of increasing atomic numbers.

‡ This is known as the Bohr and Coster number system. It specifies for each subseries all the quantum numbers known (in 1924) to be associated with it. The number outside the parenthesis is the total quantum number. In this section, the first of the two numbers in the parenthesis is regarded as the azimuthal, and the second as the inner quantum number; this is the opposite of the inter-

pretation assigned by Sommerfeld's theory.

§ This is equivalent to the preceding notation.

|| This is known as the alkali-metal-series term-system. The notation shows the optical term into which each X-ray term probably merges when followed through the series of elements to the alkali-metal in which it appears as an arc-series term. In elements a few units heavier than these alkali metals, the states of the valence electrons are quite different, and are in transition stages. The symbols are read thus: "One doublet S one," "Two doublet S one," "Two doublet P one," etc. (21, 104, 122, 139, 149, 150). Here the principal quantum numbers differ from those of (139), agreeing with more recent usage.

¶ Lyman's series-limit for H.

**Quantum Notation.**—In the Bohr and Coster number notation (17) (see Table 1), Sommerfeld's relativity doublet theory (149) assigns azimuthal quantization ( $k$ ) to the second of the two numbers in the parenthesis, but later data (122, 123) indicate that it should be assigned to the first. For this reason  $k$  will be used in this section to denote the first of these numbers, and  $j$ , the second. Thus a level will be specified by the symbol  $n(k, j)$ ; this preserves the physical significance of the symbols  $k$  and  $j$  but interchanges their assignments to the numbers used in the Bohr-Coster system. Here  $n$  is called the total,  $k$  the azimuthal, and  $j$  the inner quantum number. As they refer to different quantities,  $n$  may be  $< k + j$ .

The normal intensities here given accord with the intensity-rules postulated by Ornstein, Burger, and Dorgelo for the optical spectra of the alkali-metals (1, 3, 94). Exceptions are found when the levels are not completely filled (90); cf. (91).

At the end of the table are given the widths ( $\Delta\lambda$ ) of certain spectral lines, both in XU and in equivalent volts ( $\Delta V$ ) as defined by  $\Delta V = 12\,346 \frac{\Delta\lambda}{\lambda^2}$ , in which both  $\Delta\lambda$  and  $\lambda$  are expressed in Ångströms.

**K-Series.**  $I_r$  is independent of voltage (175).

B	Sn	B and D	D and P	Sd	Dif.	$I_r$
Bragg	Siegbahn	de Broglie and Dauvillier	Davis and Purks (53.1)	Sommerfeld	Difference	Relative inten- sity*
$\alpha_2$	$\alpha_2$	$\alpha_2$	$\alpha_2$	$\alpha'$	$K-L_{21}$	50
$\alpha_1$	$\alpha_1$	$\alpha_1$	$\alpha_1$	$\alpha$	$K-L_{22}$	100
$\beta$	$\beta_3$	$\beta_1$	$\beta_2$	$\beta'$	$K-M_{21}$	35
	$\beta_1$	$\beta_1$	$\beta_1$	$\beta$	$K-M_{22}$	
$\gamma$	$\beta_2$	$\gamma_1$	$\gamma$	$\gamma$	$K-N_{21,22}$	15
	$\beta_4$				$K-O_{21,22}$	$W^\dagger$

TABLE 2.—NOTATION, RELATIVE APPARENT INTENSITIES, AND WIDTH: NORMAL LINES

In the X-ray section of I. C. T., the Siegbahn and the difference notations are used. In each series, the several groups of closely adjacent lines are indicated in Siegbahn's notation by distinctive letters, usually Greek, and the order of the intensities of the several lines of a group is indicated by numerical subscripts, subscript 1 denoting the strongest line;  $\alpha_1, \alpha_2, \alpha_3, \dots$  is the order of decreasing intensity of the lines of the  $\alpha$ -group. The series to which a given line belongs is indicated by prefixing the series letter; e.g.,  $K\alpha_1$  is  $K-L_{21}$ ;  $L\alpha_1$  is  $L_{11}-M_{21}$ .



TABLE 2.—(Continued)

*L*-Series. Relative intensities in *L*<sub>23</sub> subseries are independent of voltage. Within each subseries, relative intensities maintain constant ratios. Intensities in *L*<sub>21</sub> and *L*<sub>11</sub> subseries are estimated on the basis of a correction to extremely high voltages, the line  $\alpha_1$  serving as a standard.

Sn	Band D	Sd	Dif.	<i>I<sub>r</sub></i>		
				74W†	78Pt†	90Th§
$\beta_4$	$\beta_4$	$\varphi'$	<i>L</i> <sub>11</sub> - <i>M</i> <sub>21</sub>	5.2		
$\beta_3$	$\beta_3$	$\varphi$	<i>L</i> <sub>11</sub> - <i>M</i> <sub>22</sub>	8.2	(8.2)	3.3
$\gamma_2$	$\gamma_7$	$\chi'$	<i>L</i> <sub>11</sub> - <i>N</i> <sub>21</sub>	1.48		1.5
$\gamma_3$	$\gamma_3$	$\chi$	<i>L</i> <sub>11</sub> - <i>N</i> <sub>22</sub>	2.01		
$\gamma_4$	$\gamma_4$	$\psi', \psi$	<i>L</i> <sub>11</sub> - <i>O</i> <sub>21,22</sub>	0.59		
	$\gamma_{8  }$		<i>L</i> <sub>11</sub> - <i>P</i> <sub>21,22</sub>			
$\eta$	$\eta$	$\eta$	<i>L</i> <sub>21</sub> - <i>M</i> <sub>11</sub>	1.3	1.5	1.8
$\beta_1$	$\beta_1$	$\beta$	<i>L</i> <sub>21</sub> - <i>M</i> <sub>32</sub>	51.8	50.8	62
$\gamma_5$	$\gamma_5$	$\kappa$	<i>L</i> <sub>21</sub> - <i>N</i> <sub>11</sub>	0.41		
$\gamma_1$	$\gamma_1$	$\delta$	<i>L</i> <sub>21</sub> - <i>N</i> <sub>32</sub>	9.1	11.1	14
$\gamma_8$	$\gamma_6, \gamma_{10}  $	$\mu$	<i>L</i> <sub>21</sub> - <i>O</i> <sub>11</sub>			
$\gamma_6$	$\gamma_3$	$\theta$	<i>L</i> <sub>21</sub> - <i>O</i> <sub>32</sub>	0.3		5.3
	$\gamma_3^{**}$		<i>L</i> <sub>21</sub> - <i>P</i> <sub>11</sub>			
<i>l</i>	<i>l</i>	$\epsilon$	<i>L</i> <sub>21</sub> - <i>M</i> <sub>11</sub>	3.2	3.4	3.6
$\alpha_2$	$\alpha_2$	$\alpha'$	<i>L</i> <sub>21</sub> - <i>M</i> <sub>32</sub>	11.5	11.4	12
$\alpha_1$	$\alpha_1$	$\alpha$	<i>L</i> <sub>21</sub> - <i>M</i> <sub>32</sub>	100.0	100.0	100.0
$\beta_6$	$\beta_6$	$\epsilon$	<i>L</i> <sub>21</sub> - <i>N</i> <sub>11</sub>	1.0		1.4
	$\beta_2$					
$\beta_2$	$\beta_2$	$\gamma', \gamma$	<i>L</i> <sub>21</sub> - <i>N</i> <sub>32,33</sub>	20.0	22.7	26
$\beta_7$	$\beta_7$	$\lambda$	<i>L</i> <sub>21</sub> - <i>O</i> <sub>11</sub>			
$\beta_5$	$\beta_5$	$\zeta', \zeta$	<i>L</i> <sub>21</sub> - <i>O</i> <sub>32, 33</sub>	0.2	3††	
	$\beta_5^{**}$		<i>L</i> <sub>21</sub> - <i>P</i> <sub>11</sub>			
$\beta_9$				0.7		
$\beta_{10}$				0.7		

*M*-Series. *I<sub>r</sub>* is photographic estimate (83, 149): no ionization measurements available. Not corrected for voltage, hence not reliable at low voltages.

Sn	Sd	Dif.	<i>I<sub>r</sub></i> *
	$\chi'$	<i>M</i> <sub>11</sub> - <i>N</i> <sub>21</sub>	0
	$\chi$	<i>M</i> <sub>11</sub> - <i>N</i> <sub>22</sub>	1
		<i>M</i> <sub>11</sub> - <i>O</i> <sub>22</sub>	0
		<i>M</i> <sub>11</sub> - <i>P</i> <sub>22</sub>	0
	$\delta$	<i>M</i> <sub>21</sub> - <i>N</i> <sub>22</sub>	1
	$\theta$	<i>M</i> <sub>21</sub> - <i>O</i> <sub>22</sub>	0
	$\eta$	<i>M</i> <sub>21</sub> - <i>N</i> <sub>11</sub>	1
$\gamma$	$\gamma'$	<i>M</i> <sub>21</sub> - <i>N</i> <sub>32</sub>	2
	$\gamma$	<i>M</i> <sub>21</sub> - <i>N</i> <sub>33</sub>	
	$\zeta'$	<i>M</i> <sub>21</sub> - <i>O</i> <sub>22</sub>	1
	$\zeta$	<i>M</i> <sub>21</sub> - <i>O</i> <sub>32</sub>	
	$\epsilon$	<i>M</i> <sub>21</sub> - <i>N</i> <sub>11</sub>	1
		<i>M</i> <sub>21</sub> - <i>O</i> <sub>11</sub>	0
$\beta$	$\beta$	<i>M</i> <sub>21</sub> - <i>N</i> <sub>42</sub>	5
		<i>M</i> <sub>21</sub> - <i>O</i> <sub>21</sub>	1
$\alpha_2$	$\alpha'$	<i>M</i> <sub>21</sub> - <i>N</i> <sub>42</sub>	1
$\alpha_1$	$\alpha$	<i>M</i> <sub>21</sub> - <i>N</i> <sub>44</sub>	8
		<i>M</i> <sub>21</sub> - <i>N</i> <sub>22</sub>	1
		<i>M</i> <sub>21</sub> - <i>P</i> <sub>22</sub>	0

*N*-Series. No values of *I<sub>r</sub>* available.

Sn	Sd	Dif.	<i>I<sub>r</sub></i> *
	$\beta$	<i>N</i> <sub>21</sub> - <i>O</i> <sub>32</sub>	
	$\alpha'$	<i>N</i> <sub>21</sub> - <i>O</i> <sub>32</sub>	
	$\alpha$	<i>N</i> <sub>21</sub> - <i>O</i> <sub>32</sub>	

TABLE 2.—(Continued)

Width of certain spectral lines (76, 77)  
Unit of  $\lambda$  and  $\Delta\lambda = 1 \text{ XU} = 0.001 \text{ \AA} = 10^{-11} \text{ cm}$ ; of  $\Delta V = 1$  volt

Line	$\lambda$	$\Delta\lambda$	$\Delta V$	
CuK $\alpha_1$	1537	0.35	1.8	
CuK $\beta_1$	1389	0.58	3.7	
MoK $\alpha_1$	708	0.19	4.8	
MoK $\beta_1$	631	0.21	6.4	±15%
MoK $\beta_2$	632	0.25	7.8	±30%
RhK $\alpha_1$	612	0.19	6.3	
RhK $\beta_1$	544	0.25	10.4	±15%
RhK $\beta_2$	545	0.30	12.4	±30%
AgK $\alpha_1$	558	0.24	9.4	
WLa <sub>1</sub>	1473	0.78	4.4	
WL $\beta_1$	1279	0.73	5.5	16††
WL $\beta_1$	1279	0.71	5.3	8††
WL $\beta_1$	1279	0.69	5.2	4††
WL $\gamma_1$	1096	0.67	6.9	12††
WL $\gamma_1$	1096	0.64	6.5	8††
WL $\gamma_1$	1096	0.53	5.4	4††

\* With reference to W unless otherwise indicated. For other values for *K*-series, see Table 6.

† Very weak.

‡ Measured by Geiger-method, and corrected for voltage and absorption (94).

§ Measured by ionization-method, and corrected for voltage and absorption (1).

|| For U (47).

¶  $\gamma_6$  for W and Ce;  $\gamma_{10}$  for Ba.

\*\* For Au (47).

†† This measurement (183, 184) was incidental to other work, and probably is less reliable than other values, but similar changes with *Z* have been observed photographically (44).

‡‡ This is the current expressed in milliamperes; 16mA, etc.

TABLE 3.—NOTATIONS: NON-DIAGRAM LINES

The I. C. T. uses Siegbahn's and difference notations

Siegbahn	Dauvillier	Duane	Difference
<i>K</i> -series (see (19)); found only in elements <i>Z</i> = 11Na to <i>Z</i> = 30Zn, and <i>Z</i> = 42Mo*			
$\alpha''$	$\alpha''$		
$\alpha'$	$\alpha_7$		
$\alpha_3$	$\alpha_2$		
$\alpha_4$	$\alpha_4$	$\alpha_3 \uparrow$	<i>K</i> - <i>L</i> <sub>11</sub>
$\alpha_5$	$\alpha_5$		
$\alpha_6$	$\alpha_6$		
$\beta'$	$\beta'$		
$\beta''$	$\beta''$		
$\beta_2 \uparrow$	$\beta_2 \uparrow$		<i>K</i> - <i>M</i> <sub>11</sub> (?) <i>K</i> - <i>N</i> <sub>22</sub> (?)
<i>L</i> -series§	$\gamma_2$		
$\beta_{10}$	$\beta_9$		<i>L</i> <sub>11</sub> - <i>M</i> <sub>32</sub>
$\beta_9$	$\beta_8$		<i>L</i> <sub>11</sub> - <i>M</i> <sub>32</sub>
$\beta_8$	$\beta_7$		<i>L</i> <sub>21</sub> - <i>N</i> <sub>3  </sub>

\* The *K*-lines found (53.2) for Mo and called  $\alpha_1, \alpha_2, \beta_1$  have not yet been identified in the accepted notations.

† Reported (88) in W spectrum with intensity (71) = 0.04 *I* K $\alpha_1$ , but Croft (42) and others have looked for it without success. It has not been reported for elements 11 to 30.

‡ Not the *K* $\beta_2$  of the normal series.

§ Nomenclature is confused, wave-length data are conflicting. The correspondences given were obtained by comparing ((142) p. 112, 172) with ((19) p. 100). For other lines, see Table 11.

|| de Broglie's notation.



## ORIGIN OF X-RAYS

**Line Spectra.**—X-rays belonging to line spectra are produced by radiation, as quanta, of the energy released in the readjustments of atoms from which electrons have been removed. The removal of such electrons may be accomplished either by direct action of cathode rays or by indirect action, through the photoelectric effect of the rays from the continuous spectrum produced by the cathode rays; rays due to these processes are called direct and indirect rays, respectively. The ratio, direct to indirect, is about 6 or 7 for Cu with 15 to 20 kv (11.1); about 1.9 for Ag with 35 to 80 kv (182). For any element, this ratio may vary somewhat with the voltage, but not rapidly.

**Continuous Spectra.**—X-rays of the continuous spectrum are probably produced by transitions of cathode rays from large to small hyperbolic orbits passing near atomic nuclei (100), or, better, between corresponding non-periodic wave systems.

In accordance with Einstein's relation, radiation of frequency  $\nu$  will not be emitted unless the energy (eV) of the impinging cathode particle is at least as great as  $h\nu$ . Hence, for each value of  $V$ , there is a definite high-frequency limit ( $\nu_0$ ) to the emitted radiation.

Such a high-frequency limit to the continuous spectrum is observed. Its value is independent of the angle the X-rays make with the cathode rays (tested for angles between 45 and 155°) (62, 170, 180), and is not changed (14) when the current density at the focal spot is varied in the ratio of 1 to 5. The ratio  $V/\nu_0$  has been studied for the elements 24Cr, 28Ni, 29Cu, 42Mo, 45Rh, 46Pd, 47Ag, 73Ta, 74W and 78Pt, and has been found to have an absolute value which is constant within the limits of experimental error; i.e., within 1% for 4.5 kv <  $V$  < 100 kv, and within 5% for 100 kv <  $V$  < 245 kv (16, 43, 64, 61, 87, 88, 107, 124, 168, 170, 174, 175, 184); general reviews (142, 171, 179). Hence  $h$  may be derived from  $V/\nu_0$ , if  $e$  is known.

PLANCK'S CONSTANT ( $h$ )

The most accurate determination of  $h$  by X-ray methods is that derived by Duane, Palmer, and Yeh (62) from the observed high-frequency limit ( $\nu_0$ ) of the continuous spectrum of W. Assuming that the grating space of calcite ( $d_c$ ) = 3.028 Å and that  $e$  and  $c$  have the values given in Vol. I, p. 17, they obtained  $h = (6.556 \pm 0.009) \times 10^{-27}$  erg sec. Using the more accurate value (140, 142),  $d_c = 3.02904$  Å, this becomes

$$h = (6.558 \pm 0.009) \times 10^{-27} \text{ erg sec}$$

which exceeds the I. C. T. value (Vol. I, p. 17) by 0.06%.

Assuming  $h = 6.558 \times 10^{-27}$  erg sec and  $e = 4.774 \times 10^{-10}$  es, exactly, Einstein's equation leads to the relations:

$$\begin{aligned} \nu_0 V &= 2.4277 \times 10^{14} \text{ (volt sec)}^{-1} \\ &= 2.4287 \times 10^{14} \text{ (Int. volt}^* \text{ sec)}^{-1} \\ V\lambda_0 &= 1.2352 \times 10^4 \text{ volt Å} \\ &= 1.2346 \times 10^4 \text{ Int. volt}^* \text{ Å} \end{aligned}$$

## LINE SPECTRA

**General Characteristics.**—In the characteristic line spectrum of any element, most of the lines can be distributed among a small group of series and subseries in accordance with the conception of energy-levels. Every line in any series is regarded as arising from the return of an electron to some one of the levels composing a single group, and all lines belonging to the same subseries involve the same group with the same electronic readjustments during ionization. In any given subseries, no line appears unless (eV) is at least equal to  $h\nu_0$ , where  $\nu_0$  is the highest frequency represented in the subseries;  $\nu_0$  is a characteristic of the subseries, and is known as the subseries limit. The value of  $V_0 = h\nu_0/e$  is called the *excitation voltage* of the subseries; it may be computed from

\* Defined by the relation: Weston normal cell = 1.018300 Int. volt at 20°C.

data in Table 10 or from the wave-length of the absorption limit (Table 11) of the subseries. The former method is probably the more accurate. Certain values of  $V_0$  are given in (142). Accuracy of confirmatory data is about 1% (45, 85, 88, 137, 169, 174, 175, 178, 184, 196). The distribution of electrons in atoms and the transitions involved in the emission of characteristic X-rays are indicated in Figs. 1 and 2.

The lines which do not obey the laws followed by the normal series are referred to anomalous energy-levels. All these lines are very faint and may arise from multiple ionization (35, 46, 189) but opinions differ regarding their sources (see, e.g. (6)). Hence, data and notations pertaining to anomalous levels must be considered as tentative only. All lines not definitely related to the normal levels and those not obeying the selection rules (p. 31) will be called *non-diagram* lines, and will be designated by the notation used by the investigator quoted. For excitation voltages of certain non-diagram lines, see Table 9, 13Al, 26Fe, and 42Mo.

The various symbols which are used for specifying the energy-levels, series and subseries are given in Table 1.

Proceeding in the order of the atomic numbers, the spectra of successive elements are found to be very similar, and to undergo a regular displacement from element to element (Figs. 3 and 4); for any given line, this displacement is such that  $\sqrt{\nu}$  is nearly linear in  $Z$  (Moseley's law) (v. Table 4). Lines so related may be called corresponding lines. Semi-optical lines (cf. Fig. 4) occupy anomalous positions.

Bäcklin (7, 8) and Ray (134) have shown that, when one of the lighter elements (13Al, 14Si, 15P, 16S) enters into certain chemical compounds, the wave-length of its  $K\alpha$ -lines is slightly changed; the following differences, expressed in x-units (1 XU = 0.001 Å), were observed by Bäcklin (7): Al and  $Al_2O_3$ ,  $\delta\lambda = 1.72$ ; Si and  $SiO_2$ ,  $\delta\lambda = 2.34$ ; red P and either  $P_2O_5$  or  $Na_3PO_4$ ,  $\delta\lambda = 2.72$ ; and S and  $BaSO_4$ ,  $\delta\lambda = 3.05$ . Likewise their  $K\beta$  lines change both in intensity and wave-length (115, 116, 117, 120, 129, 130).

TABLE 4.—VARIATION OF FREQUENCY WITH ATOMIC NUMBER

If  $\nu_\infty = 3.29057 \times 10^{15} \text{ sec}^{-1}$ , and  $\nu$  is the frequency of a given line in the spectrum of the element of atomic number  $Z$ , then\*  $\sqrt{\nu/\nu_\infty} = a + bZ(10)^{-3} + cZ^2(10)^{-6}$ . With the values of the coefficients given below, the computed value of  $\sqrt{\nu/\nu_\infty}$  is seldom in error by as much as 0.2 unit, if  $Z > Z_0$ .

Line	Difference	$a$	$b$	$c$	$Z_0$
$Ll$	$L_{21}-M_{11}$	-2.99	369	-191	37
$L\alpha_1$	$L_{21}-M_{12}$	-2.09	352	+159	29
$L\eta$	$L_{21}-M_{11}$	-1.13	280	+1051	36
$L\beta_1$	$L_{11}-M_{21}$	-0.45	287	+1041	36
$L\beta_1$	$L_{21}-M_{22}$	-0.44	274	+1264	29
$L\beta_2$	$L_{11}-M_{22}$	+0.06	263	+1345	36
$L\beta_2$	$L_{21}-N_{12,23}$	-3.82	412	+81	39
$L\gamma_1$	$L_{21}-N_{12}$	-2.29	338	+1116	39
$L\gamma_2$	$L_{11}-N_{21}$	-1.54	333	+1126	36
$L\gamma_2$	$L_{11}-N_{22}$	-1.26	321	+1244	36
$L\gamma_4$	$L_{11}-O_{21,22}$	-1.33	324	+1315	48
	$L_{11}$ -limit	-0.37	288	+1638	46
	$L_{21}$ -limit	-0.45	274	+1712	46
	$L_{22}$ -limit	-3.20	384	+400	46
$K\alpha_2$	$K-L_{21}$	+0.12	788	+1406	10
$K\alpha_1$	$K-L_{22}$	-0.03	798	+1330	10
$K\beta_1$	$K-M_{21}$	-0.71	868	+1246	10
$K\beta_2$	$K-N_{22}$	-0.47	856	+1587	22
	$K$ -limit	-0.60	862	+1539	11

\* Computed in editorial office from data (142) submitted by Expert. No attempt to get a "best fit."—Ed.



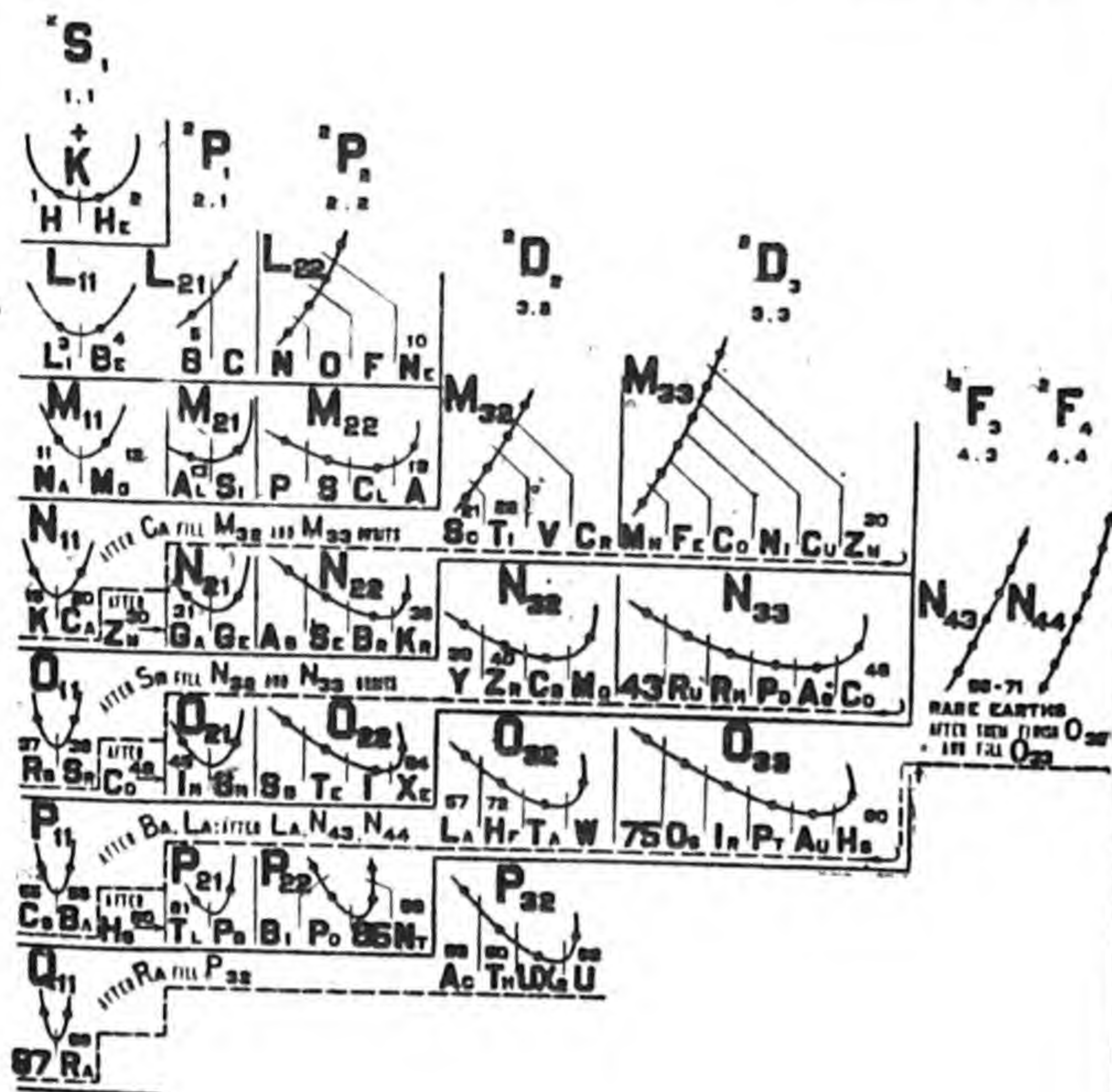


FIG. 1.—Distribution of electrons in atoms according to Stoner's modification (194) of Bohr's theory.

For discussion of experimental evidence, see (10, 22, 149, 151, 156). Each energy-level, presumably corresponding to a group of orbits, is represented by an arc with as many dots as there are electrons in the heaviest element. The number of such electrons for a given element is indicated by the distribution of the dots. The shape of the arc indicates qualitatively the probable character of the orbit. Evidence more recent than Stoner's theory (v. Slater (146)) indicates that the distinction between orbits differing only in an inner quantum number (e.g.,  $L_{21}$  and  $L_{22}$ ) may be the unreal; that, for example, all 6 electrons in the  $L_{21}$  and  $L_{22}$  orbits may belong to a single group, and that the division in  $2L_{21}$ 's and  $4L_{22}$ 's may be merely a statistical expression of the chances of 2 forms of readjustment of the group when one electron is removed.

Each element contains as many electrons as there are units in its atomic number, distributed, in general, as follows: Beginning at the top and proceeding in order of atomic numbers, the electrons in an element are distributed in accordance with all the dots up to and including that associated with its own symbol; e.g., of the 13 electrons of Al, 2 are in each of the orbits  $K$ ,  $L_{11}$ , and  $L_{21}$ , 4 in  $L_{22}$ , 2 in  $M_{11}$ , and 1 in  $M_{21}$ . This rule is fairly certain for all elements in the  $S$ -column, but the  $P$  orbits are not always filled in the order indicated and exceptions are very probable in the filling of the  $D$  and the  $F$  orbits; and any incomplete group (such as a group of 4  $P$ -electrons) of equal total quantum number becomes a unit giving rise to series more complex than doublets.

In general, the X-ray spectrum of an element will contain no normal X-ray line which involves a level not shown in this diagram, but exceptions occur; e.g., the line  $K-M_{21,22}$ , arising from a temporary occupancy of the  $M_{21,22}$  orbits (10), is observed in the spectrum of Na and Mg. As compared with the usual normal lines, these lines occupy an anomalous position in the spectrum (see Fig. 4); they are called semi-optical lines.

Univalent Cu probably takes one of its  $N_{11}$  electrons to complete  $M_{32}$ ; Ag one of its  $O_{11}$ 's into  $N_{32}$ ; and Au, one of its  $P_{11}$ 's into  $O_{32}$ .

The rare earths (58 to 71), Sc21, Yt39, La57, and Ac89, all have similar sets of valence electrons (those beyond the outermost X-ray orbit).

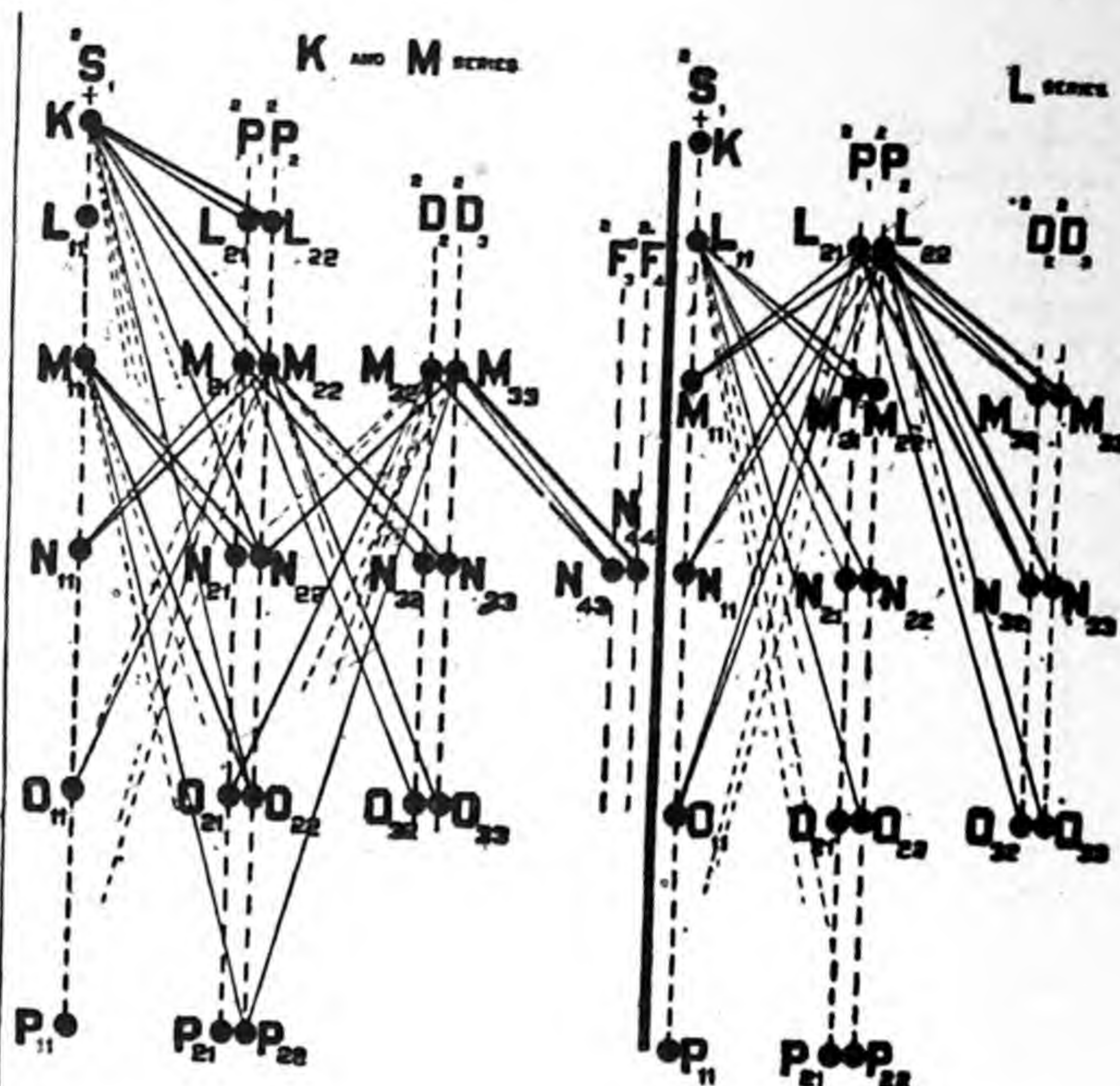


FIG. 2.—Transitions involved in emission of lines of the  $K$ -,  $L$ -,  $M$ -series.

Each type of electron orbit (arc of Fig. 1) is represented by a dot; its distance from the + above the  $K$ -dot represents the average radius of the orbit. In general, the electrons in the orbits corresponding to any horizontal row in the figure are bound more firmly than those in the row below; and those near the left end of a row, more firmly than those near the right. The symbol at the head of a column indicates the general type of energy level produced by ionization from an orbit of the type shown in that column (see Table 1). The sloping lines indicate the transitions which accord with the selection principles (p. 31), and their thicknesses indicate the relative intensities of the resulting spectral lines; if dotted and incomplete, the corresponding spectral line has not been observed, presumably because it is very weak or lies too near a strong line.

**Regular Doublets.**—In each spectrum a series of pairs of lines can be found such that  $\Delta\nu$  is the same for each pair; e.g., in the spectrum of W the following frequency differences are observed where  $\nu_\infty = 3.29057 \times 10^{16} \text{ sec}^{-1}$ :

Lines.....	$\eta-l$	$\beta_1-\alpha_2$	$\gamma_5-\beta_6$	$\gamma_1-\beta_2$	$\gamma_6-\beta_5$	$L_{21}-L_{22}$	$K(\alpha_1-\alpha_2)$
$\Delta\nu/\nu_\infty$ .....	98.75	98.54	99.00	98.05	98.51	98.71	98.5
Level.....	$M_{11}$	$M_{32}$	$N_{11}$	$N_{32}$	$O_{32}$	Limit	$K$

Each pair can be traced from element to element by means of Moseley's law as applied to the individual lines. It is thus found that, except for certain significant irregularities<sup>1</sup> (v. Figs. 5, 6),  $\Delta\lambda$  for any one pair is nearly the same for every element (cf. Fig. 7). Such pairs of lines are called *regular*, or *relativity*, doublets and are regarded as arising from the transfer of electrons between one common energy-level,  $n(k, j)$ , and one or other of two adjacent levels,  $n'(k', j')$ ,  $n'(k', j' + 1)$ , belonging to another group and differing by one unit in  $j'$ . If the element is a constituent of a chemical compound, the value of  $\Delta\lambda$  depends upon the nature of the compound; variations of nearly 10% may be so caused (v. Table 5).

<sup>1</sup> When the doublet-distance is abnormal, the lines of the doublet are more or less complex; i.e., the system is really a multiplet.



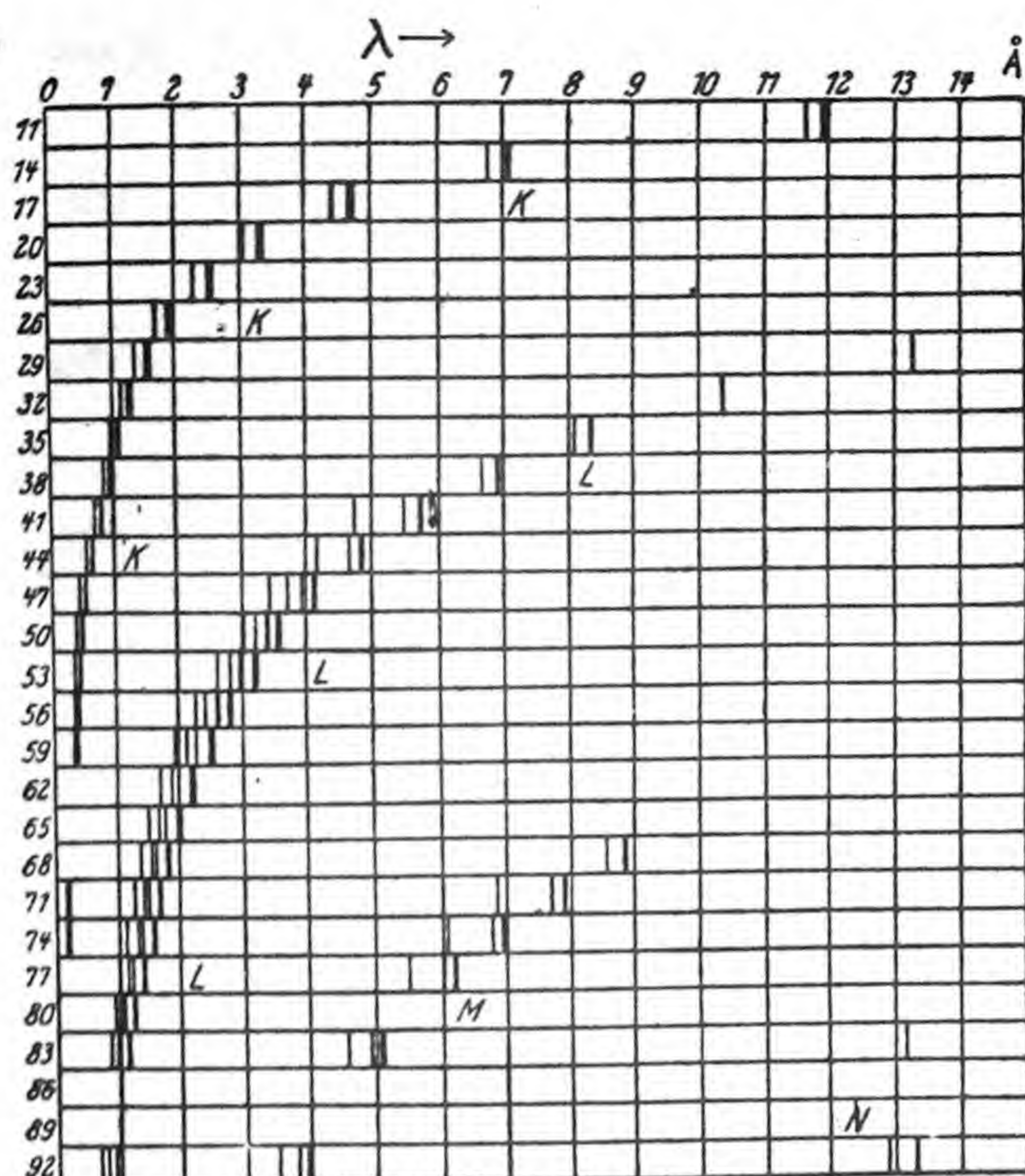


FIG. 3.—The strongest normal lines of the X-ray spectrum of every third element from  $Z = 11$  to  $Z = 92$ . (After Siegbahn (142).)

Shows the relative positions of the several series and their changes from element to element.

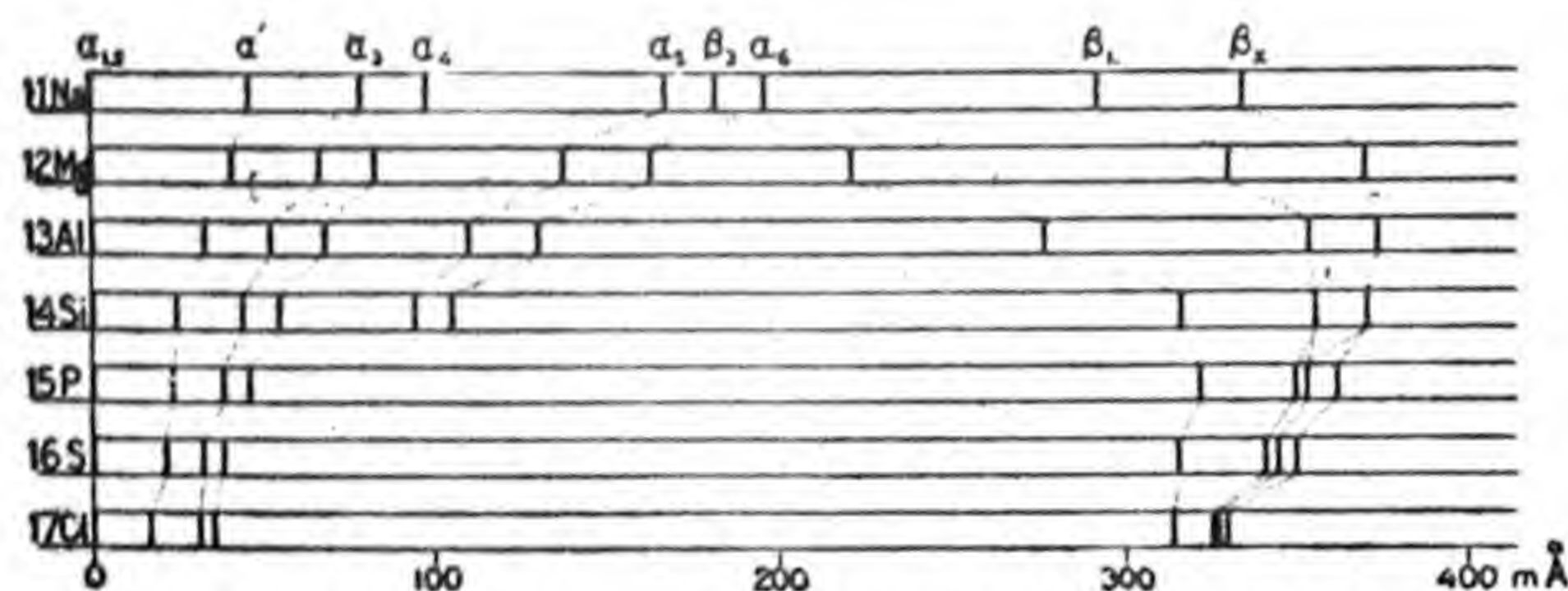


FIG. 4.—Position of certain lines of the  $K$ -series with reference to  $K\alpha_{1,2}$ .

Numbers on the scale indicate  $\Delta\lambda$  as measured from  $K\alpha_{1,2}$ . Note the anomalous position of the semi-optical lines  $K\beta_3$ ,  $K\beta_1$ , and  $K\beta_2$  in 11Na, 12Mg, 13Al, and 14Si, which normally contain no electron in the  $M_{12}$ -orbit (cf. Fig. 1).

TABLE 5.—REGULAR DOUBLET SEPARATION: EFFECT OF CHEMICAL COMBINATION (133)

$\Delta\lambda$  = difference in the wave-lengths of the two components of the doublet  $K-L_{21}$ ,  $K-L_{22}$  of element named in column (1). Unit of  $\Delta\lambda = 0.001 \text{ Å} = 10^{-11} \text{ cm}$ .

1	Compound	$\Delta\lambda$	1	Compound	$\Delta\lambda$
Cl	KCl.....	3.15	Fe	Fe (powder).....	4.20
	BaCl <sub>2</sub> .....	3.15		Fe(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> .....	4.13
	KClO <sub>3</sub> .....	2.99		FeNH <sub>4</sub> (SO <sub>4</sub> ) <sub>2</sub> .....	4.01
	Ba(ClO <sub>3</sub> ) <sub>2</sub> .....	2.98		K <sub>4</sub> Fe(CN) <sub>6</sub> .....	4.06
	KClO <sub>4</sub> .....	2.92		K <sub>3</sub> Fe(CN) <sub>6</sub> .....	3.99
K	KCl.....	3.40	V	V (powder).....	3.68
	KClO <sub>3</sub> .....	3.22		NH <sub>4</sub> VO <sub>3</sub> .....	3.60
	KClO <sub>4</sub> .....	3.16			

**Irregular Doublets.**—Another type of doublet, found in series limits, is characterized by the fact that  $\Delta\sqrt{\nu}$  for a given doublet is nearly the same for every element (see Fig. 8,  $L_{11}$ ,  $L_{21}$ ;  $M_{11}$ ,  $M_{21}$ ;  $M_{22}$ ,  $M_{32}$ ;  $N_{11}$ ,  $N_{21}$ ;  $N_{22}$ ,  $N_{32}$ ;  $N_{33}$ ,  $N_{43}$ ;  $O_{11}$ ,  $O_{21}$ ;  $O_{22}$ ,  $O_{32}$ ; also cf.  $L_{11}$ - and  $L_{21}$ -limit, Table 4). These are called *irregular*, or *screening*, doublets and involve a pair of levels differing by one unit in  $k$ . Consequently, their appearance in lines is forbidden by the selection rule for  $k$ , and, when found, the forbidden line of the doublet is very faint.

Doublets of both types are found in the ultra-violet and the visible spectra of stripped atoms (122, 123).

**Screening Numbers.**—The frequency limit ( $\nu_0$ ) of the series  $n(k, j)$  is related to  $Z$  and the quantum numbers as indicated (149) by eq. (1):

$$\frac{\nu_0}{\nu_\infty} = \frac{1}{n^2}(Z - S)^2 + \frac{\alpha^2}{n^4}(Z - s)^4 \left( \frac{n}{j} - \frac{3}{4} \right) + \frac{\alpha^4}{n^6}(Z - s)^6 \left[ \frac{1}{4} \left( \frac{n}{j} \right)^3 + \frac{3}{4} \left( \frac{n}{j} \right)^2 - \frac{3n}{2j} + \frac{5}{8} \right] + \dots \quad (1)$$

where  $\alpha^2 (= 2\pi e^2/hc\epsilon_0) = 5.31 \times 10^{-5}$ ,  $\epsilon_0$  = dielectric constant of a vacuum, and  $S$  and  $s$  are empirical *screening numbers* which are derived (190) from data for doublets, and are to be interpreted as measures of the amount by which the external system of electrons reduces the intensity of the electrical field acting upon the returning electron. Excepting the  $K$ -level, for which there is only one value of  $j$ , the value of  $s$  for any level can be obtained from the observed value of  $\Delta\nu$  for the corresponding regular doublets, by inserting in eq. (1) the two values of  $j$  and subtracting, it being known that  $\Delta\nu_0 = \Delta\nu$ . Knowing  $s$ ,  $S$  is computed from  $\nu_0$  by means of eq. (1). It depends upon  $Z$ , is independent of  $j$ , but varies with  $k$ , and is, thus, associated with irregular doublets. It is found that the difference ( $\Delta S$ ) corresponding to the levels  $n(i, i)$  and  $n(i + 1, i)$  is  $\Delta S = 0.57n2^{i-1}$ ; probably  $\Delta S$  is independent of  $Z$ ; observed irregularities are only a few per cent and are believed to arise from errors.

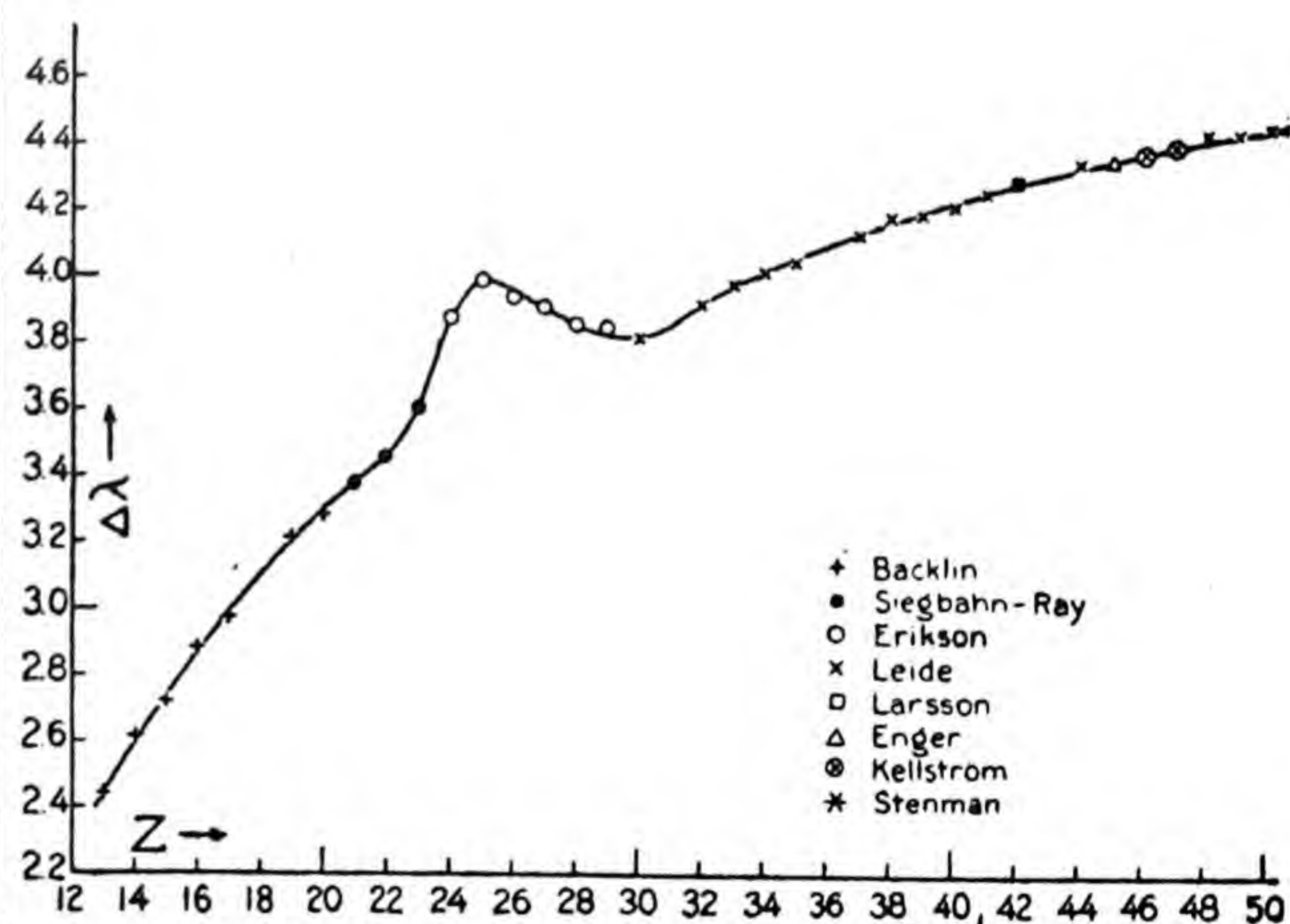


FIG. 5.—Irregularities in the separation of the components of the  $K\alpha$  doublet (7, 78, 79, 96, 106, 109, 144).

$$\Delta\lambda = \lambda_{K\alpha_2} - \lambda_{K\alpha_1}; \text{ unit} = 1 \text{ XU} = 1 \text{ mÅ} = 10^{-11} \text{ cm}.$$

For values of  $S$ , see Fig. 9 or (190). For  $K$ -level,  $s = S$ ; for ( $L_{21,22}$ ),  $s = 3.492 \pm 0.07$  if  $41\text{Cb} \leq Z \leq 92\text{U}$  (149); for  $[n(i, i - 1), n(i, i)]$ ,  $s = 4.23(n - 2)i$  if  $n > 2$ , and is nearly independent of  $Z$  except for  $n = 4$ ,  $i = 4$ , for which  $s$  decreases with  $Z$  (149). For certain irregularities, see Figs. 5, 6.



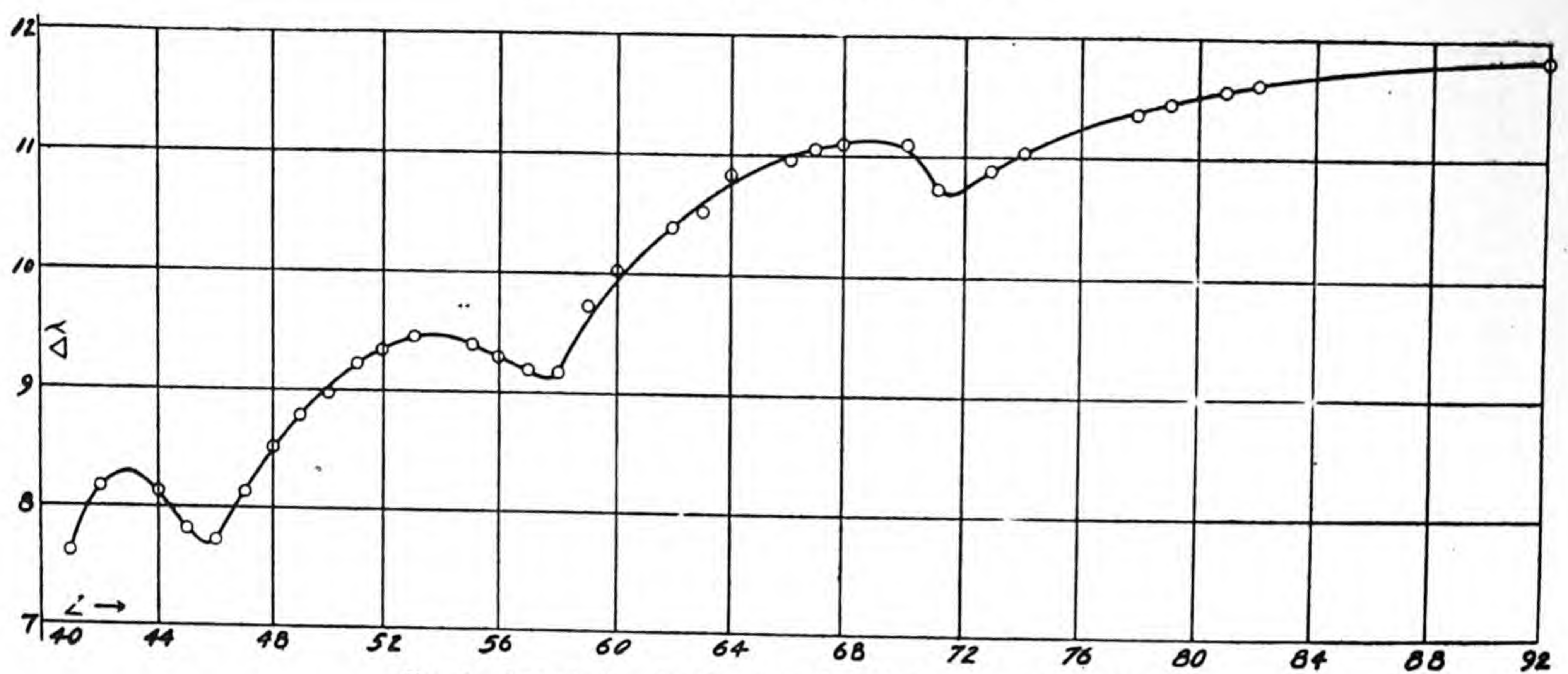


FIG. 6.—Irregularities in the separation of the  $L\alpha$  doublet (132).  
Unit of  $\Delta\lambda = 1\text{m}\text{\AA}$ .

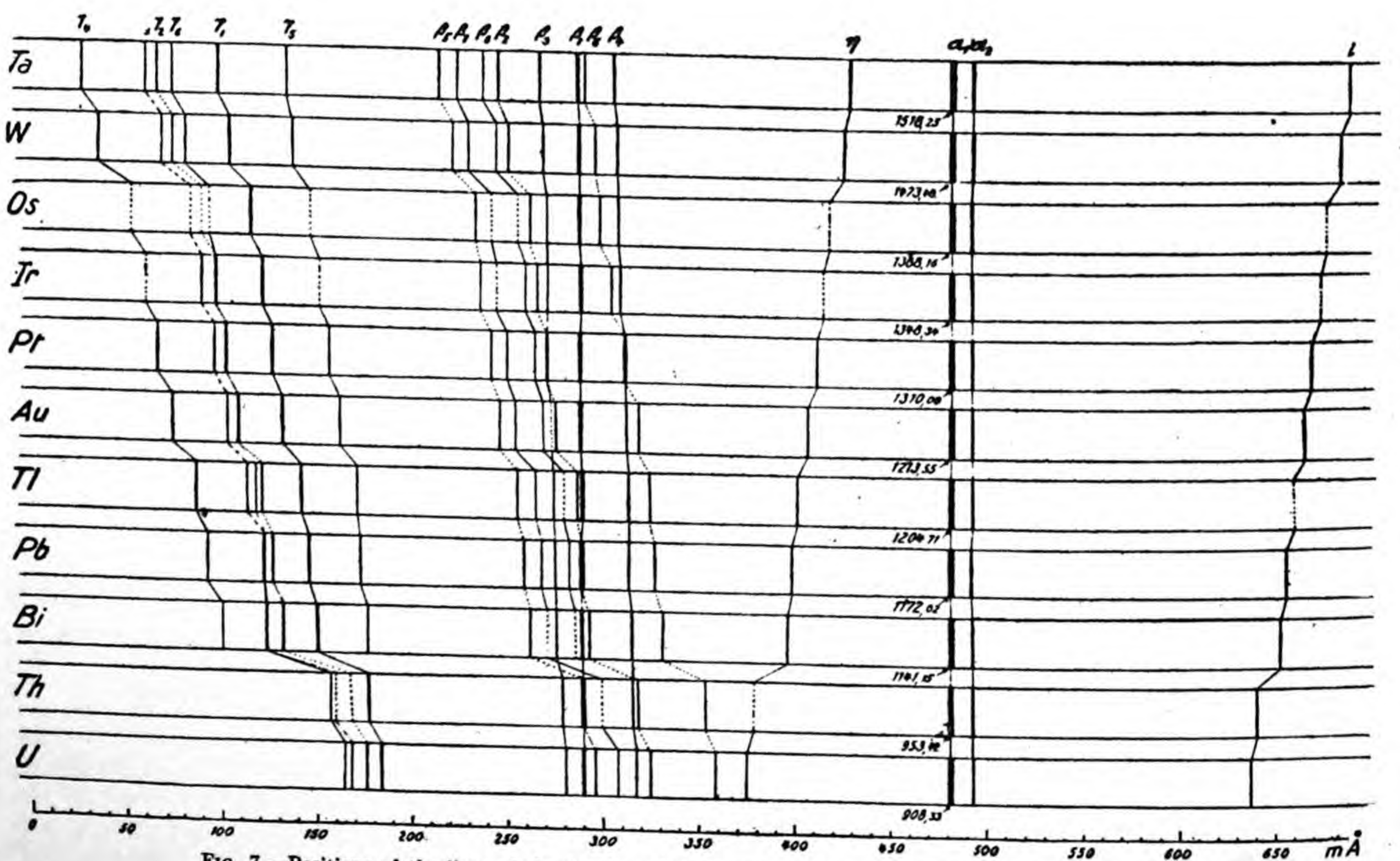


FIG. 7.—Positions of the lines of the  $L$ -series with reference to  $L\alpha_1$ . (After Siegbahn (143).)  
For each element the actual wave-length of its  $L\alpha_1$  is indicated. Unit of  $\lambda = 1\text{m}\text{\AA} = 10^{-11}\text{ cm}$ .



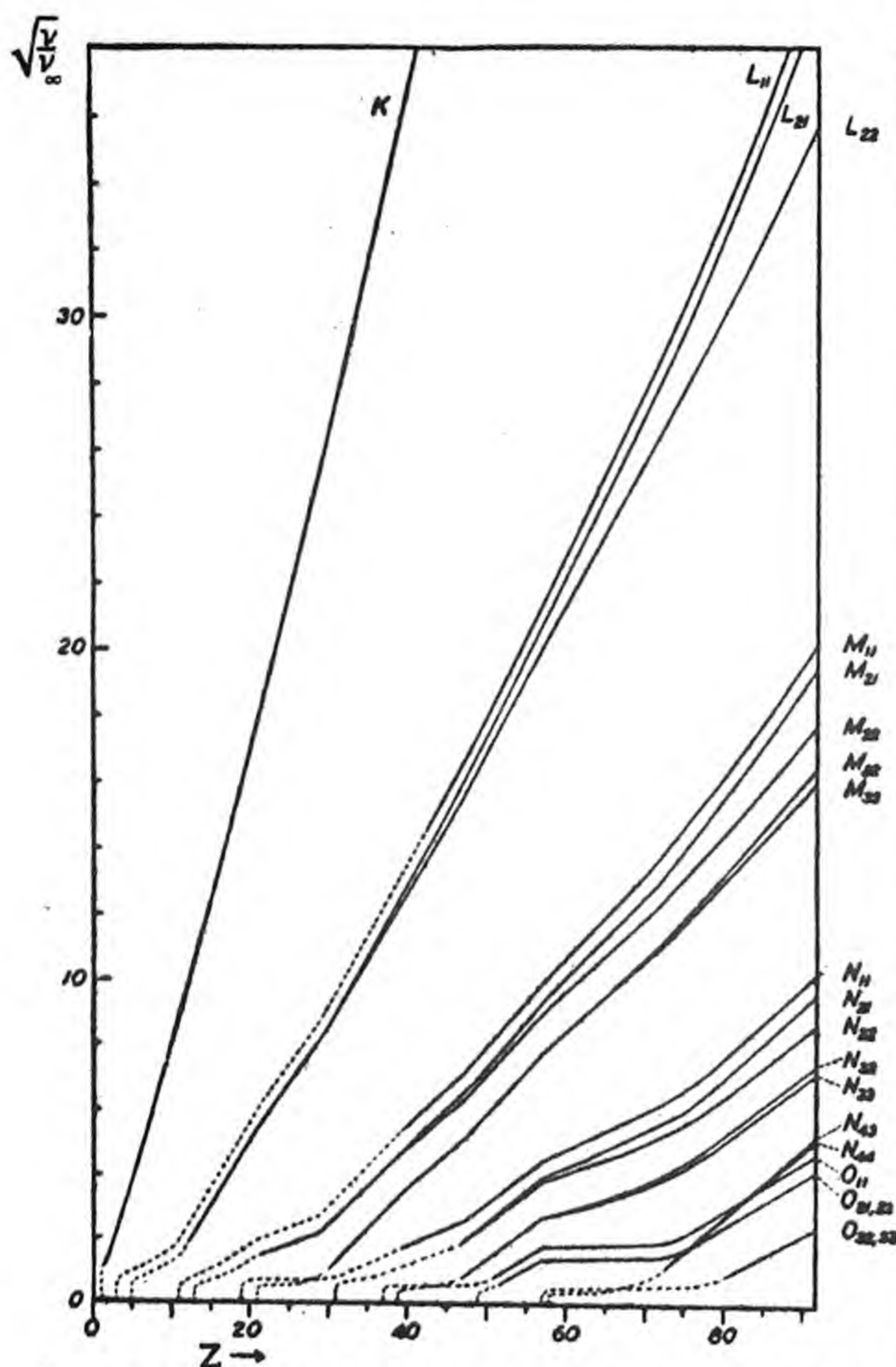


FIG. 8.—Bohr and Coster's Moseley diagram of the limits of the series. (After Siegbahn (143).)

The notation has been changed to that of Sommerfeld (see Table 1).  $\nu_{\infty} = 3.29057 \times 10^{15} \text{ sec}^{-1}$ . Nishina (127) gives a more detailed diagram of the  $M$ -,  $N$ -, and  $O$ -limits of elements 50 to 74.

**Selection Principles.**—It is observed that transitions corresponding to the stronger lines always occur in the direction  $n(k, j)$  to  $n'(k', j')$ , where  $n' = n - x$ ,  $k' = k + y$ ,  $j' = j + z$ , and each of the quantities  $x, y, z$  has one of the "allowed" values indicated below.

	Allowed	
	Values <sup>a</sup>	Examples
$x$	+1, 2, 3 . . .	$M_{21} \rightarrow L_{11}, O_{11} \rightarrow L_{21}$
$y$	-1, +1	$M_{21} \rightarrow L_{11}, M_{11} \rightarrow L_{21}$
$z$	-1, +1, 0	$M_{22} \rightarrow L_{21}, N_{22} \leftrightarrow M_{22}, N_{21} \rightarrow L_{11}$
	Forbidden	
	Values	Examples
$x$	$\leq 0$	$L_{22} \rightarrow L_{11}, L_{22} \rightarrow M_{22}$
$y$	$0, \pm > 1$	$M_{22} \rightarrow L_{22}, O_{22} \rightarrow N_{22}, N_{22} \rightarrow M_{22}$
$z$	$\pm > 1$	$N_{21} \rightarrow M_{22}, M_{22} \rightarrow L_{21}$

With the exception of requiring that  $x \neq 0$ , these selection principles are identical with those of a normal doublet system in an optical series. They refer to probabilities, and consider nothing

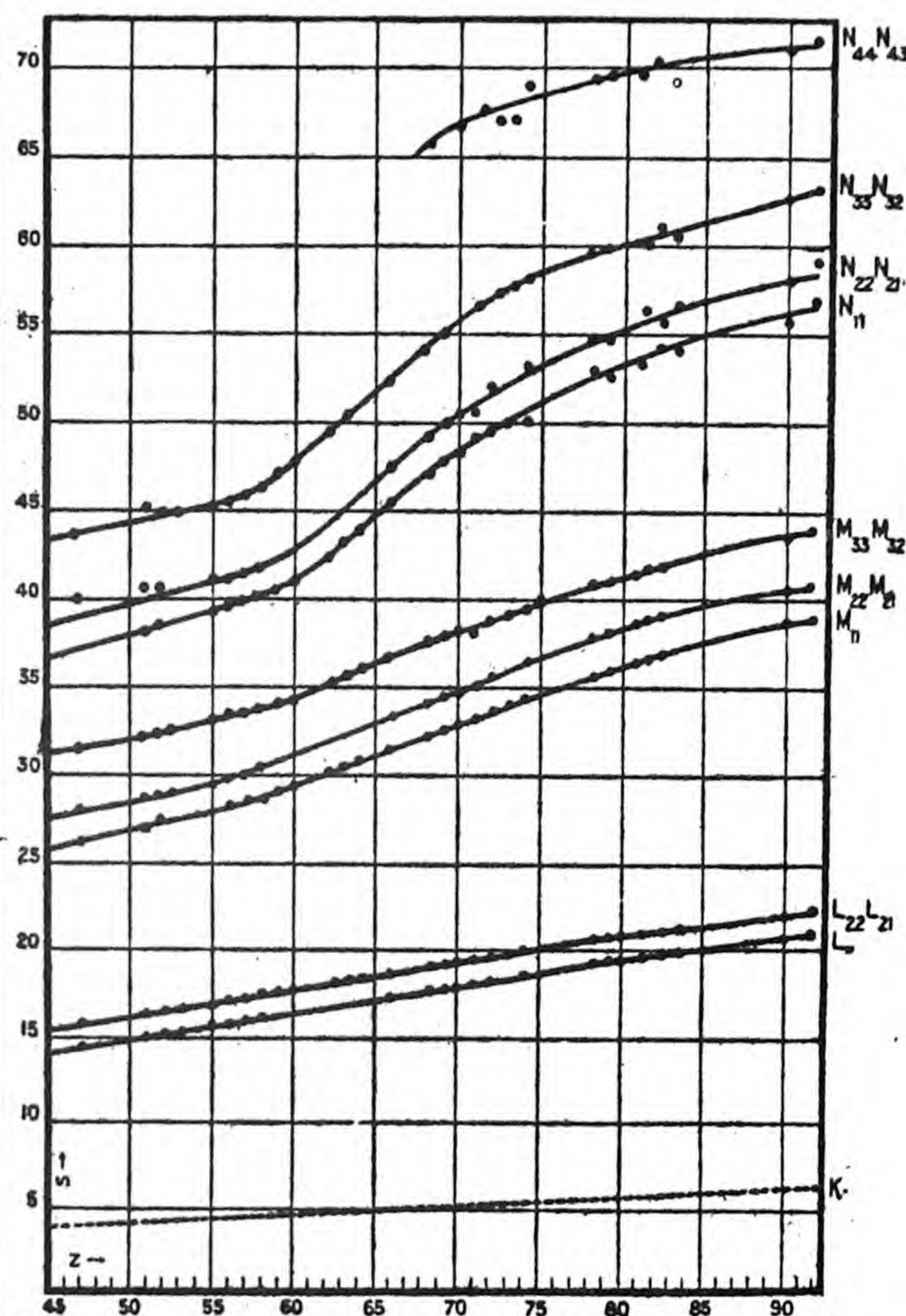


FIG. 9.—Values of screening number  $S$  for various energy-levels and atomic numbers (149); cf. p. 29.

but the structure of the isolated atom. Whenever the atom contains no electron of a particular group (as e.g., normal Cu contains no  $O_{11}$ -electron) the levels due to ionization from that group do not give rise to any line in its spectrum; if such electrons are present only in optically excited atoms, the lines are semi-optical and are abnormal in position, cf. Fig. 4.

The only possible violation of the total quantum selection principle ( $x \neq 0$ ) which would give a line in the X-ray region is  $L_{11}-L_{22}$ . This line has been sought (35, 33) but not found, although in the optical region this transition corresponds to the strongest (red) line in the Li spectrum. Violations of the other selection principles (regarding  $x$  and  $y$ ) are quite common (see Tables 3, 11), but it is reported (5) that no forbidden line of the  $L$ -series is so much as 0.001 as intense as  $L_{22}-M_{22}$ . All lines violating any of the selection principles are extremely weak and, in this section, are classed as non-diagram lines.

**Intensities of Lines** (see also Tables 2, 6).—**Variation with Energy-Level.**—For a given tube potential, the relative intensities of the lines are determined by the energy-levels involved and the probabilities ( $P$ ) of the several transitions. In the preceding table, the allowed values of  $x, y$ , and  $z$  are arranged, in each case, in the order of decreasing values of  $P$ ; the three sets may be regarded as mutually independent. Also, for given values of  $x, y, z$ , and  $n$ , the intensity increases with the values of  $j$  and of  $k$ .

For transitions of the type  $n(k, j)-n'(k', j')$  where  $k = k + 1$ ,  $j = k$  or  $k - 1$ ,  $j' = k$  or  $k + 1$ , and  $n$  and  $n'$  are two given positive



integers, the relative values of  $P$  are as follows (103, 149, 150), where  $i$  denotes the numerical value of  $k$ :

	Transition	$P(4i^2 - 1)$	Example	$i$	$P(4i^2 - 1)$
a	$n(i, i) - n'(i + 1, i + 1)$	$2i^2 + i - 1$	$L_{17} - M_{11}$	2	9
b	$n(i, i - 1) - n'(i + 1, i)$	$2i^2 - i - 1$	$L_{21} - M_{12}$	2	5
c	$n(i, i) - n'(i + 1, i)$	1	$L_{17} - M_{12}$	2	1
d	$n(i, i - 1) - n'(i + 1, i + 1)$	0	$L_{21} - M_{11}$	2	0

If the lines form a close doublet, their intensities ( $J$ ) are essentially proportional to  $P$ .

For the special case of  $i = 1$  (orbits of the  $^3S_1$  type), only transitions  $a$  and  $c$  are possible and  $P_a = 2P_c$ ; e.g.,  $P(K - L_{22}) = 2P(K - L_{21})$ . If  $i = 2$ ,  $P_a + P_c = 2(P_b + P_d)$  and  $2(P_a + P_d) = 3(P_b + P_c)$ . For confirmatory data, see (149).

Values of  $P$  for other types of transition have not yet been definitely determined, but a first approximation to a total quantum rule has been given (86).

**Relative Intensities within a Given Subseries.**—The ratio of the apparent intensities ( $I_p$ ) of any two lines in the same subseries is independent of the tube potential (169, 174, 175, 184, 196). Examples of its variation with  $Z$  are given in Table 6.

TABLE 6.—RELATIVE APPARENT INTENSITIES ( $I_2/I_1$ ) OF NORMAL LINES OF K-SERIES; VARIATION WITH  $Z$

$(\beta_3 + \beta_1 + \beta_2 + \beta_4)/(\alpha_1 + \alpha_2)$				
$Z$	Obs.*	Tube*	Targ.*	Lit.
24Cr	0.313	0.136	0.0810	(169)
29Cu	0.213	0.153	0.136	(169)
	0.165†			(147)
30Zn	0.193†			(147)
42Mo	0.251	0.180	0.175	(196)
	0.20†			(50)
45Rh	0.176	0.210	0.168	(169)
	0.158			(175)
46Pd	0.189	0.160	0.139	(196)
47Ag	0.167	0.215	0.207	(169)
	0.20†			(50)
74W	0.33			(68)

$I/I\alpha_1$				
$Z$	$\alpha_2$	$\beta_{3,1}$	$\beta_2$	Lit.
26Fe	0.50	0.26†	<< 0.05†	(142, 147)
29Cu				
30Zn				
42Mo	0.50§	0.30§	0.05§	(50, 67, 196)
74W	0.50	0.35	0.15	(71)

For all of these,  $\beta_4$  is very faint

\* Obs. = observed, values depend upon instrumental equipment; Tube = values within tube, after correction for various losses by absorption, reflection, etc.; Targ. = values within target, i.e., as emitted by atom. The Targ. values are far from accurate; recent work (185) indicates that the corrections for target absorption have usually been too great.

† By photographic photometry.

‡ Values may be seriously in error, but  $\beta_{3,1}/\beta_2$  is probably correct within 2 or 3 %.

§ Data (50, 67) for  $\alpha_2$  and  $\beta_{3,1}/\beta_2$  have been combined with data (196) for  $(\beta_3 + \beta_1 + \beta_2 + \beta_4)/(\alpha_1 + \alpha_2)$ . (See column Obs.) Values for  $\beta_{3,1}$  and  $\beta_2$  uncertain by 0.05 $\alpha_1$ .

**Variation with Tube Voltage.**—The formulae that have been proposed for the variation of the line intensity with the tube voltage are listed in Table 7; formulae (1) and (2) are empirical; the others are theoretical, (5) having the best theoretical basis. In all five,  $I$  is defined for each line as the power radiated per unit solid angle and per electron in the cathode ray current. It is the product of three factors: The quantum  $h\nu$ ; the probability that an

electron will cause the emission of such a quantum (this is very small, as very few of the electrons give rise to X-rays); and the fraction of the quanta that is not absorbed within the target.  $C_1$  and  $C_2$  are independent of  $V$ , but are functions of  $\lambda$ , of direction from the target surface, etc.  $C_3$  and  $C_4$  are constants for any one line.  $K^2 = \mu \csc \epsilon_x / b \csc \epsilon_c$ , where  $\mu$  is the absorption coefficient of the target for the X-rays considered, and  $b$  is its stopping power for the cathode rays ( $v_x^2 = v_0^2 - bx$ ,  $v$  = velocity),  $\epsilon_x$  and  $\epsilon_c$  are the angles the X-rays and the cathode rays make with the surface of the target.  $N$  = number of such electrons per unit volume as are of the type required for the excitation of the line considered (e.g., for a  $K$ -line,  $N$  = twice the number of atoms per unit volume);  $T = E/eV_0$ , where  $E$  = kinetic energy of the electron in its orbit;  $U = V/V_0$ ;  $u$  = probability that a removal of an electron of the proper type will actually result in an emission of a quantum of the line considered;  $V$  = tube voltage;  $V_0$  = excitation potential;  $V_1$  an empirically determined potential that exceeds  $V_0$ ;  $\nu$  = frequency;  $e$  and  $h$  have their usual significance.

TABLE 7.—FORMULAE FOR VARIATION OF LINE INTENSITY WITH TUBE VOLTAGE

For symbols and discussion of formulae, see adjacent text

No.	Formula	Lit.
(1)	$I = C_1(V - V_0)^n$ $V_0 < V < 2V_0$	(1, 92, 184)
(2)	$I = C_2(V^2 - V_1^2)$ $1.5V_0 < V < 3V_0$	(97, 169, 196)
(3)	$I = C_3 \left[ \frac{1}{K^2} \left( 1 - e^{-K^2(V^2 - V_0^2)} \right) - \frac{2V_0}{K} e^{-K^2 V^2} \int_{KV_0}^{KV} e^{y^2} dy \right]$	(52)
(4)	$I = C_4 e^{-K^2 V^2} \left[ \frac{1}{V} \int_{V_0}^V e^{-K^2 y^2} dy - \int_{V_0}^V \frac{1}{y} e^{-K^2 y^2} dy \right]$	(92)
(5)	$I = \frac{Ne^2 u h \nu}{6b} \left[ (U - 1)(2T + 3) - \frac{2T}{T + 1} \log \left( \frac{U(T + 2)}{U + T + 1} \right) - \{3 + (T + 1)(2T + 3)\} \log \left( \frac{U + T + 1}{T + 2} \right) \right]$	(160.1)

In formula (1),  $n$  is about 1.5 for rays subject to great absorption in target (emerging at small angles); for other rays,  $n = 1.7$  to 2.1.

Formula (2) refers to rays subject to small absorption in target;  $V_1$  is about  $1.2V_0$  to  $1.5V_0$ , but is often misquoted as  $V_0$ .

It appears that in formula (3) the correction for absorption in target is several times too great unless  $V - V_0$  is small (185). If  $K = 0$ , this formula reduces (92) to  $I = C_3(V - V_0)^2$ , which is a special case of (1), but is often misquoted as  $C_3(V^2 - V_0^2)$ , and confused with (2). At times,  $K$  is treated as an arbitrary constant, its definition being ignored ((97); cf. Fig. 11). For shape of graph defined by this equation, see Fig. 10.

In formula (4) also, the correction for absorption in the target is too great;  $K$  is frequently treated as an empirical constant. For graphs defined by (4), see (92); they are much like those of Figs. 10 and 11.

Formula (5) is proposed for circular orbits only ( $K$ ,  $L_{21}$ ,  $L_{22}$ ,  $M_{12}$ ,  $M_{13}$ ,  $N_{13}$ ,  $N_{14}$ ), and contains no correction for absorption in target. With an arbitrary unit of intensity, it fits the data (196) for  $K$ -series of Mo42 the best of all (160.1); and data (182) for Ag47 indicate (though with large probable error) that it is good also for absolute intensity, but only for the directly produced rays (see p. 27), i.e., for about 65% of the rays of the  $K$ -series of Ag.

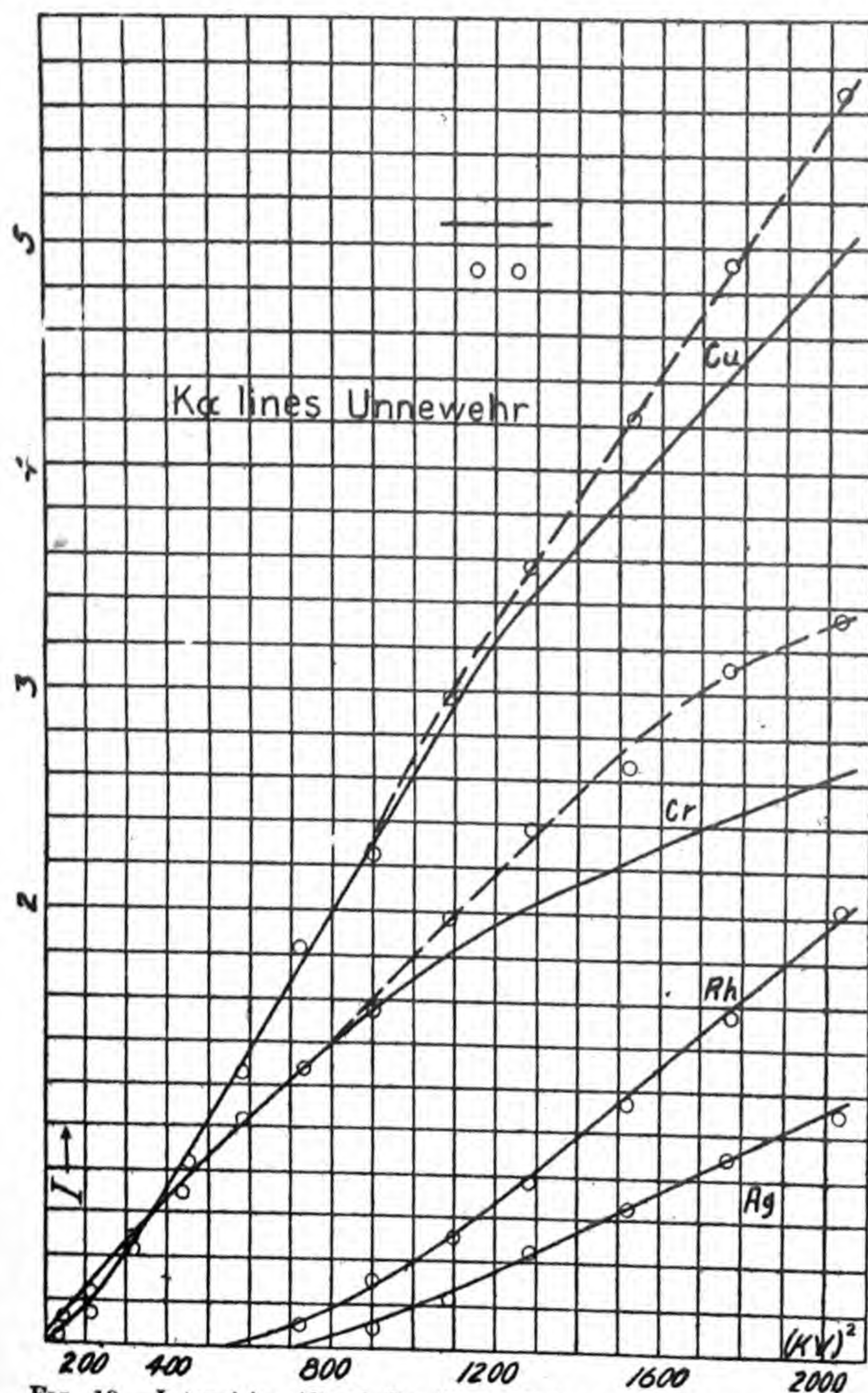
**Ratio of Line Intensity to Intensity of Continuous Spectrum.**—If  $I_l$  = intensity of the line (= power radiated per unit solid angle in the direction considered) and if  $I_c d\lambda$  = power radiated per unit solid angle in the same direction by a strip of continuous spectrum of length  $d\lambda$ , then the ratio of the two intensities may be specified by  $\Delta\lambda$  as defined by the equation  $I_l = \int_{\lambda - \frac{1}{2}\Delta\lambda}^{\lambda + \frac{1}{2}\Delta\lambda} I_c d\lambda$ , where  $\lambda$  is the wave-length of the line. In Figs. 12 and 13 the ordinates are proportional to  $\Delta\lambda$ . For illustrative values of  $\Delta\lambda$ , see Table 8.



TABLE 8.—RATIO OF LINE INTENSITY TO INTENSITY OF CONTINUOUS SPECTRUM

$I_l = \int_{\lambda - \frac{1}{2}\Delta\lambda}^{\lambda + \frac{1}{2}\Delta\lambda} I_c d\lambda$ ;  $\lambda$  = wave-length of line  $l$ ; tabular values are  $\Delta\lambda/\lambda$ ; probable error for Ag is 10%; for Cd, 5%; unit of  $V$  = 1000 volt = 1 kv.

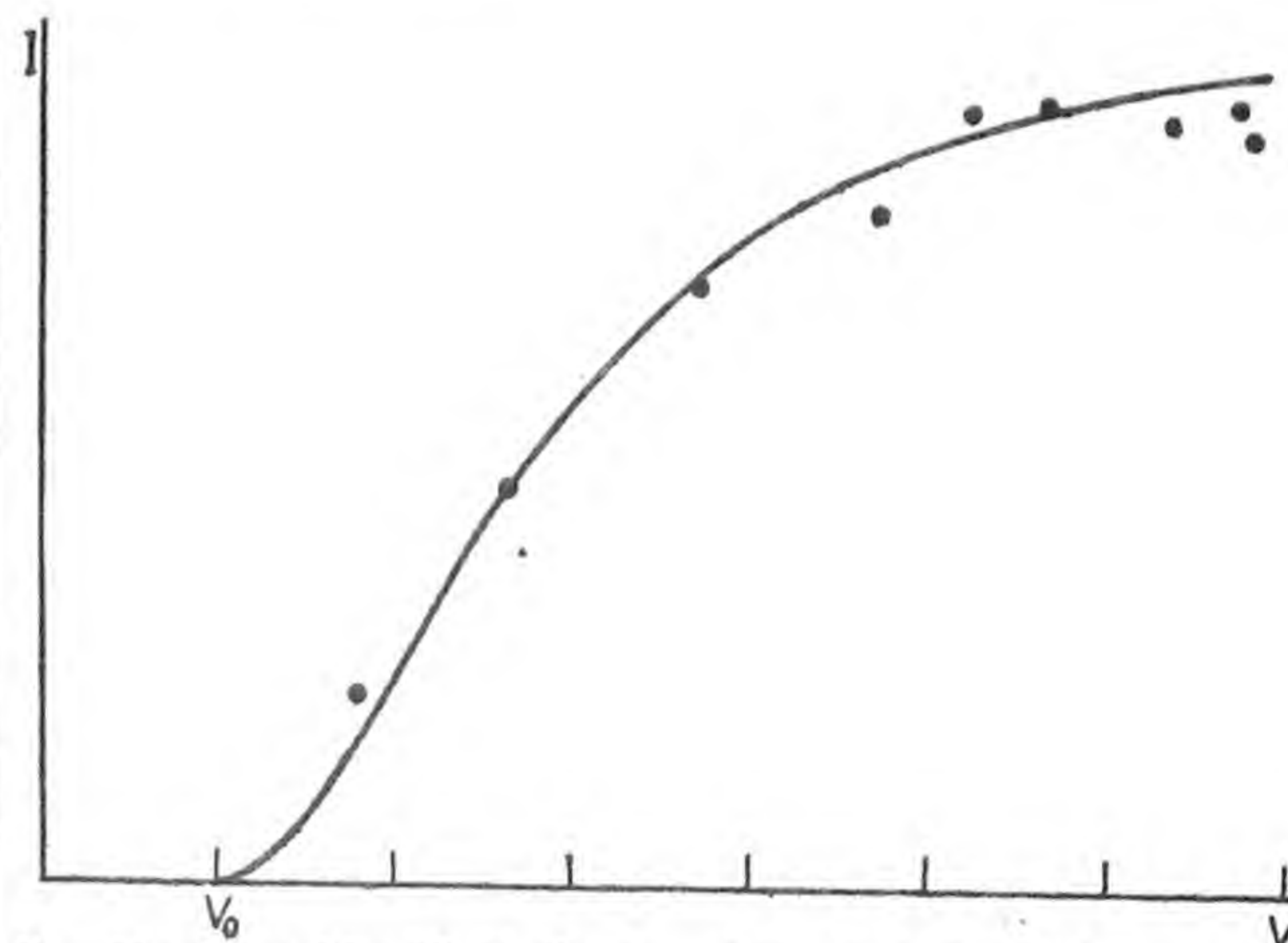
Line	Rays	V	35	50	65	80
AgK $\alpha$ doublet.....	Direct		0.10	0.24	0.31	0.41
AgK $\alpha$ doublet.....	Indirect		0.055	0.13	0.16	0.21
AgK $\alpha$ doublet.....	Total		0.15	0.37	0.47	0.62
CdK $\alpha$ .....	Total		0.125	0.32	0.45	0.58
CdK $\beta\gamma$ .....	Total		0.034	0.075	0.10	0.13

FIG. 10.—Intensities ( $I$ ) of  $K\alpha$  lines: Variation with potential ( $V$ ) (169).

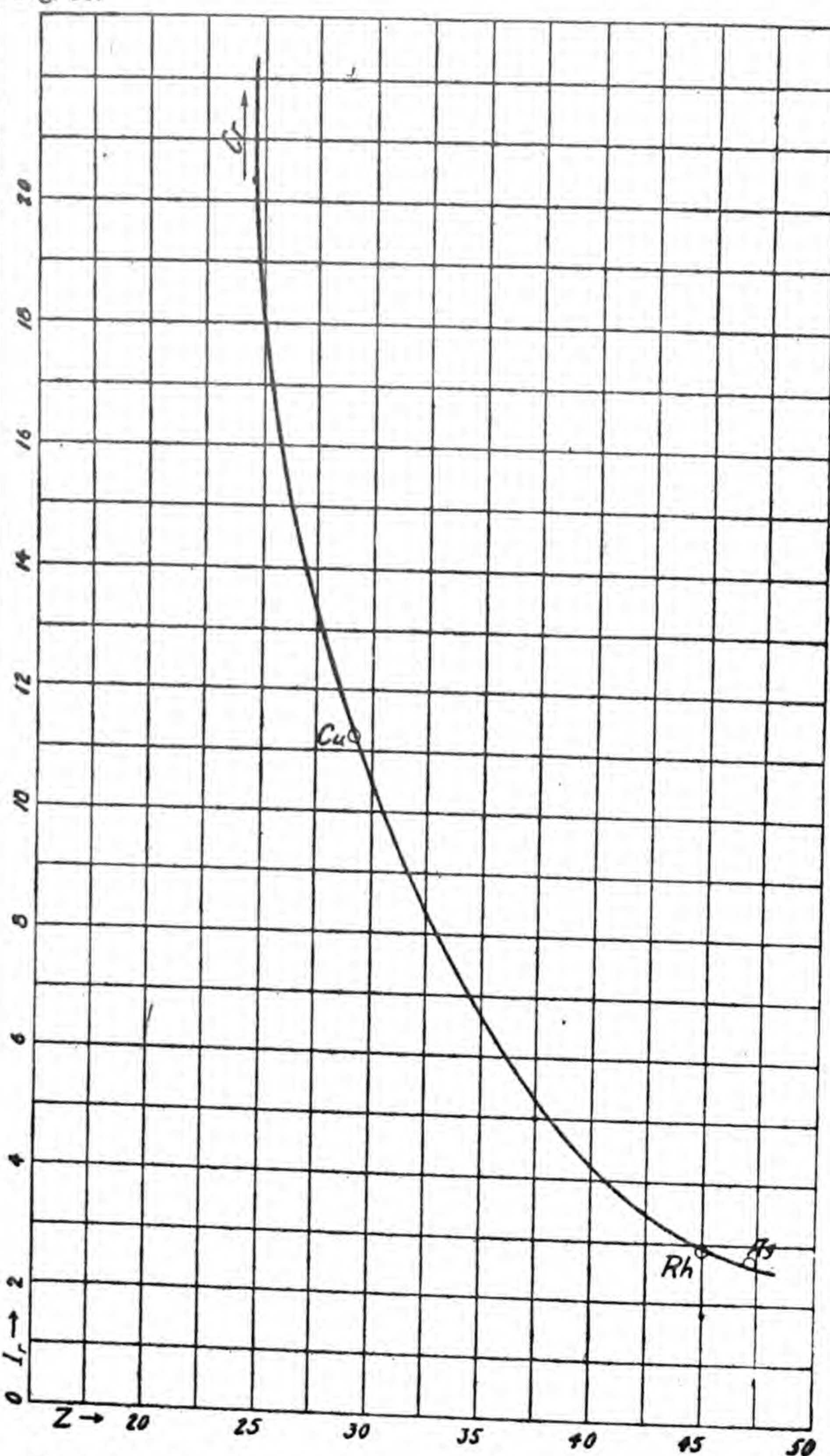
Solid lines represent Bergen Davis' equation (see p. 32). Unit of  $I$  is arbitrary; of  $V$  = 1000 volt; cf. Fig. 11.

TABLE 9.—PRIMARY STANDARDS OF WAVE-LENGTH\*

All values are based upon Siegbahn's value (28, 140, 142) of ( $d_c$ ) the grating space for calcite in the first order,  $d_c = 3.02904 \text{ \AA}$  (or, more exactly,  $\log_{10} 2d_c = 0.7823347$ ), or its equivalent value for rock salt,  $d_r = 2.81400 \text{ \AA}$  ( $\log_{10} 2d_r = 0.7503541$ ); when necessary, the data have been recomputed; these are marked with an  $r$ . This value of  $d_c$  exceeds the I. C. T. value (Vol. I, p. 18) by 3,435 parts in 10 000. Only those data marked with a  $c$  have been corrected for refraction by the crystal (cf. (142)). For Lang's system of secondary standards based on  $K\alpha_1$  for Cu as

FIG. 11.—Intensities ( $I$ ) of  $K\alpha_1$  line of Cr: Variation with potential ( $V$ ) (27).

Solid line represents Bergen Davis' equation (see p. 32) with  $K$  regarded as a constant to be determined from the observations; cf. Fig. 10.

FIG. 13.—Ratio ( $I_r$ ) of intensities of  $K\alpha$  line to the same width of continuous spectrum in the same region: Variation with atomic number ( $Z$ ) (169).



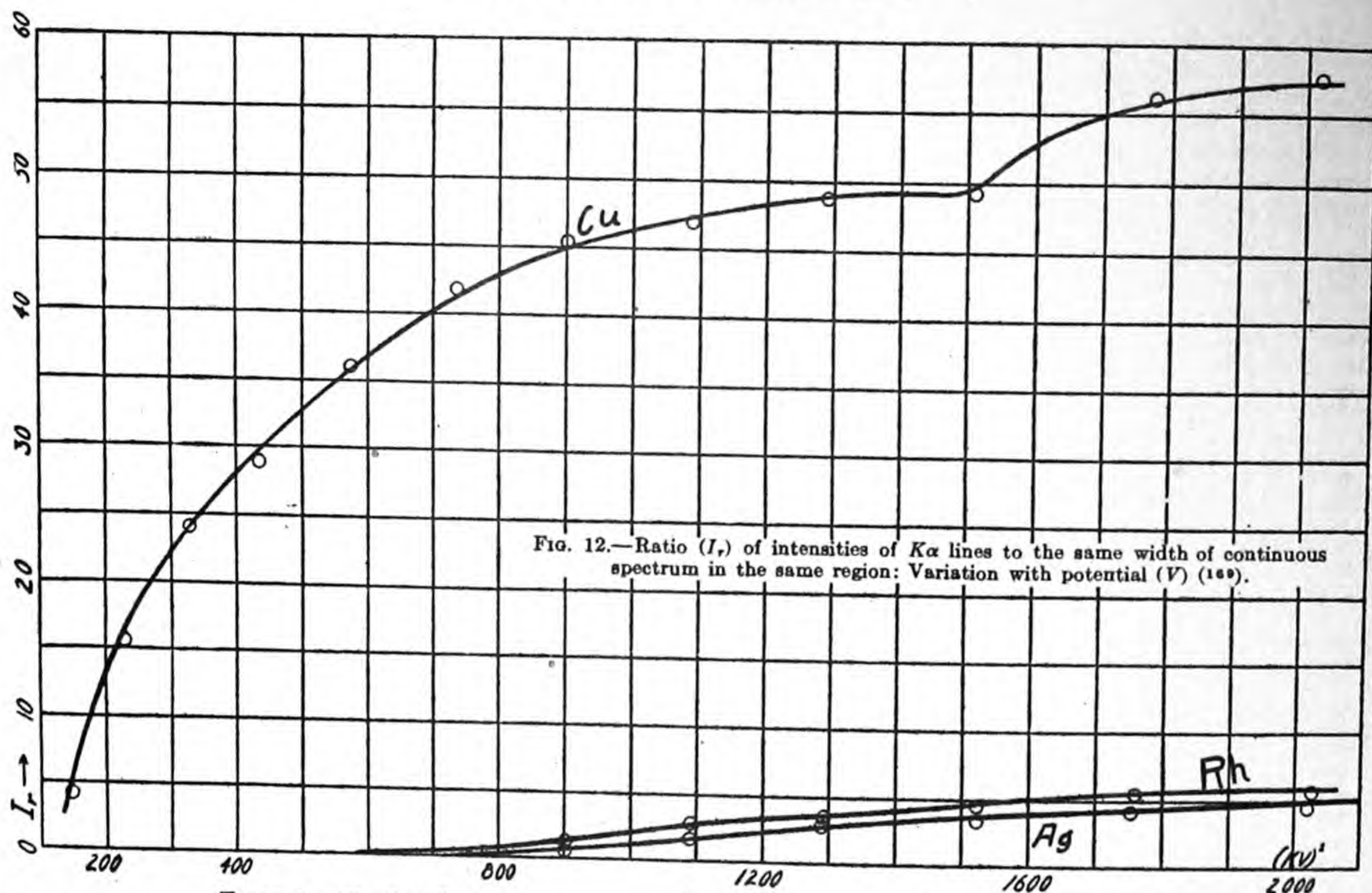


FIG. 12.—Ratio ( $I_r$ ) of intensities of  $K\alpha$  lines to the same width of continuous spectrum in the same region: Variation with potential ( $V$ ) (100).

TABLE 9.—(Continued)

$\lambda = 1537.30\text{m}\mu$ , see (105); his values for  $\lambda$ 's of most prominent lines of 76Os, 77Ir, 78Pt, 79Au, 82Pb, and 83Bi average  $0.48\text{m}\mu$  greater than Coster's (142).

Line = Siegbahn's notation, see Table 2;  $\theta$  = observed glancing angle for maximum intensity;  $\lambda$  = wave-length; P. E. = probable error in  $\lambda$ ; unit of  $\lambda = 1\text{m}\mu = 0.001\text{ \AA} = 10^{-11}\text{ cm}$ .

	Line	$\theta$	Crystal	$\lambda$	P. E.	Lit.
26Fe	$K\alpha_1$	18° 38' 13.2"	Calcite	1935.987		(106)
	$K\alpha_2$	18 35 52.3	Calcite	1932.066		(106)
29Cu	$K\alpha_1$	14 42 0.3	Calcite	1537.29	st†	(108)
	$K\alpha_2$	16 31 31.5	Pyrite r	1537.75c	0.15	(125)
			Mean	1537.52		
	$K\beta_1$	14 53 39.0	Pyrite r	1389.63c	0.15	(125)
74W	$L\alpha_1$	14 11 0.0	Calcite	1484.38		(81)
	$L\alpha_2$	14 4 32.9	Calcite	1473.36		(81)
	$L\beta_1$	12 11 23.5	Calcite	1279.17		(81)
	$L\beta_2$	11 49 50.4	Calcite	1242.03		(81)
	$L\gamma_1$	10 25 33.5	Calcite	1096.30		(81)
35Br	K-limit		NaCl	918.6		(131)
	K-limit		Calcite r	918.2	‡	(60)
			Mean	918.4		
	K-limit	8 43 0	Calcite	918.09		(109)
	D. R. ††	8 7 48	NaCl	795.9	<0.1	(131)
42Mo	$K\alpha_1$		Calcite	712.105		(106)
	$K\alpha_2$		Calcite	712.175		(2)
	$K\alpha_3$	6 42 35.3	Calcite	707.831		(106)
	$K\alpha_4$		Calcite	707.865		(2)
	$K\beta_1$		Calcite	631.543		(106)
	$K\beta_2$		Calcite	631.657		(2)
	$K\beta_3$	5 58 42.5	Calcite	630.978		(106)
	$K\beta_4$		Calcite	631.094		(2)
	$K\beta_5$		Calcite	619.698		(106)
	$K\beta_6$		Calcite	619.823		(2)
47Ag	K-limit		NaCl	484.2		(131)
	K-limit		Calcite r	485.2	‡	(60)
			Mean	484.7		
	K-limit	4 35 24	Calcite	484.80		(109)
	D. R. ††		NaCl	431.6	<0.1	(131)
74W	$K\alpha_1$		Calcite	213.52	**	(141)
			Calcite r	213.48‡	0.03	(71)

TABLE 9.—(Continued)

	Line	$\theta$	Crystal	$\lambda$	P. E.	Lit.
74W	$K\alpha_1$		Calcite	213.69	0.08	(32)
			(?)	213.41	0.1	(135)
			Mean	213.55		
	$K\alpha_2$	1 58 27.6	Calcite	208.71	st‡	(108)
		1 58 32.6	Calcite	208.85	**	(141)
			Calcite r	208.67‡	0.04	(71)
			Calcite	208.84	0.08	(32)
			(?)	208.50	0.1	(135)
			Mean	208.71		
	$K\beta_1, \beta_2$	1 44 38	Calcite	184.36	**	(141)
			Calcite r	184.26‡	0.03	(71)
			Calcite	184.56	0.08	(32)
			(?)	184.16	0.1	(135)
			Mean	184.34		
	$K\beta_3$	1 41 49	Calcite	179.40	**	(141)
			Calcite r	179.07‡	0.06	(71)
			Calcite	179.07	0.25	(32)
			(?)	179.00	0.1	(135)
			Mean	179.13		
	K-limit		Calcite r	178.12‡	0.07	(71)
			NaCl	178.02	††	(42)
			Mean	178.07		

\* When it is not convenient to replace the X-ray tube by one of the elements here listed, the absorption limits of Br and of Ag are the most convenient standards. They always appear in photographically recorded spectra, and when ionization methods are used one of them may be introduced by using  $\text{CH}_3\text{Br}$  in the ionization chamber or by inserting Ag foil (0.005 to 0.01 cm thick (43)) into the path of the rays.

† Grating space of calcite in second order is  $3.02935\text{ \AA}$  ( $\log_{10} = 0.4813494$ ), in third order it is  $3.02940\text{ \AA}$  ( $\log_{10} = 0.4813566$ ).

‡ Mean value, individual values differ from mean by  $\leq 0.05\text{m}\mu$ . Later measurements, not yet published, give systematically somewhat higher values. Hence, for the present, the  $\text{Fe}K\alpha_1$  line is to be preferred as standard for the longer wave-lengths; the value here given for its wave-length was measured with the same instrument and crystal as the newest, most accurate measurements of (78, 79, 81, 86, 106, 152). "st" indicates that the data were used by Leide as standards. A newer, but unpublished, measurement of the Cu  $K\alpha_1$  line with calcite crystal gives  $\lambda = 1537.39$ .

§ Settings estimated to 0.1% of  $\theta$ . || Double reflection line. ¶ From spectra of high order. \*\* Mean values; individual values of  $\theta$  differ from mean by ca. 3."

†† Based upon Siegbahn's values for K emission lines.



TABLE 10.—LIMITING FREQUENCIES ( $\nu_0$ ) OF X-RAY SERIES (17, 27, 40, 41, 127, 157, 162, 163)

In general, both emission and absorption data have been used in the calculation of the following values; they are more accurate than if they depended upon absorption alone.

If  $h/e = 1.37285 \times 10^{-17}$  erg sec es $^{-1}$  (I. C. T. value, Vol. I, p. 17) and  $\nu_\infty = 3.29057 \times 10^{15}$  sec $^{-1}$  (not I. C. T. value), then the excitation potential is  $V_0 = 13.546 \nu_0/\nu_\infty$  absolute volt =  $13.5404 \nu_0/\nu_\infty$  international volt (v)\* ( $\log_{10} 13.5461 = 1.1318141$ ;  $\log_{10} 13.5404 = 1.1316317$ ). Tabular values are  $\nu_0/\nu_\infty$ , where  $\nu_\infty = 3.29057 \times 10^{15}$  sec $^{-1}$ .

	K	L <sub>11</sub>	L <sub>21</sub>	L <sub>22</sub>	M <sub>11</sub>	M <sub>21</sub>	M <sub>22</sub>	M <sub>32</sub>	M <sub>33</sub>	N <sub>11</sub>	N <sub>21</sub>	N <sub>22</sub>	N <sub>23</sub>	N <sub>24</sub>	N <sub>25</sub>	N <sub>26</sub>	N <sub>27</sub>	N <sub>28</sub>	N <sub>29</sub>	N <sub>30</sub>	N <sub>31</sub>	N <sub>32</sub>	N <sub>33</sub>	N <sub>34</sub>	N <sub>35</sub>	N <sub>36</sub>	N <sub>37</sub>	N <sub>38</sub>	N <sub>39</sub>	N <sub>40</sub>	N <sub>41</sub>	N <sub>42</sub>	N <sub>43</sub>	N <sub>44</sub>	N <sub>45</sub>	N <sub>46</sub>	N <sub>47</sub>	N <sub>48</sub>	N <sub>49</sub>	N <sub>50</sub>	N <sub>51</sub>	N <sub>52</sub>	N <sub>53</sub>	N <sub>54</sub>	N <sub>55</sub>	N <sub>56</sub>	N <sub>57</sub>	N <sub>58</sub>	N <sub>59</sub>	N <sub>60</sub>	N <sub>61</sub>	N <sub>62</sub>	N <sub>63</sub>	N <sub>64</sub>	N <sub>65</sub>	N <sub>66</sub>	N <sub>67</sub>	N <sub>68</sub>	N <sub>69</sub>	N <sub>70</sub>	N <sub>71</sub>	N <sub>72</sub>	N <sub>73</sub>	N <sub>74</sub>	N <sub>75</sub>	N <sub>76</sub>	N <sub>77</sub>	N <sub>78</sub>	N <sub>79</sub>	N <sub>80</sub>	N <sub>81</sub>	N <sub>82</sub>	N <sub>83</sub>	N <sub>84</sub>	N <sub>85</sub>	N <sub>86</sub>	N <sub>87</sub>	N <sub>88</sub>	N <sub>89</sub>	N <sub>90</sub>	N <sub>91</sub>	N <sub>92</sub>	N <sub>93</sub>	N <sub>94</sub>	N <sub>95</sub>	N <sub>96</sub>	N <sub>97</sub>	N <sub>98</sub>	N <sub>99</sub>	N <sub>100</sub>	N <sub>101</sub>	N <sub>102</sub>	N <sub>103</sub>	N <sub>104</sub>	N <sub>105</sub>	N <sub>106</sub>	N <sub>107</sub>	N <sub>108</sub>	N <sub>109</sub>	N <sub>110</sub>	N <sub>111</sub>	N <sub>112</sub>	N <sub>113</sub>	N <sub>114</sub>	N <sub>115</sub>	N <sub>116</sub>	N <sub>117</sub>	N <sub>118</sub>	N <sub>119</sub>	N <sub>120</sub>	N <sub>121</sub>	N <sub>122</sub>	N <sub>123</sub>	N <sub>124</sub>	N <sub>125</sub>	N <sub>126</sub>	N <sub>127</sub>	N <sub>128</sub>	N <sub>129</sub>	N <sub>130</sub>	N <sub>131</sub>	N <sub>132</sub>	N <sub>133</sub>	N <sub>134</sub>	N <sub>135</sub>	N <sub>136</sub>	N <sub>137</sub>	N <sub>138</sub>	N <sub>139</sub>	N <sub>140</sub>	N <sub>141</sub>	N <sub>142</sub>	N <sub>143</sub>	N <sub>144</sub>	N <sub>145</sub>	N <sub>146</sub>	N <sub>147</sub>	N <sub>148</sub>	N <sub>149</sub>	N <sub>150</sub>	N <sub>151</sub>	N <sub>152</sub>	N <sub>153</sub>	N <sub>154</sub>	N <sub>155</sub>	N <sub>156</sub>	N <sub>157</sub>	N <sub>158</sub>	N <sub>159</sub>	N <sub>160</sub>	N <sub>161</sub>	N <sub>162</sub>	N <sub>163</sub>	N <sub>164</sub>	N <sub>165</sub>	N <sub>166</sub>	N <sub>167</sub>	N <sub>168</sub>	N <sub>169</sub>	N <sub>170</sub>	N <sub>171</sub>	N <sub>172</sub>	N <sub>173</sub>	N <sub>174</sub>	N <sub>175</sub>	N <sub>176</sub>	N <sub>177</sub>	N <sub>178</sub>	N <sub>179</sub>	N <sub>180</sub>	N <sub>181</sub>	N <sub>182</sub>	N <sub>183</sub>	N <sub>184</sub>	N <sub>185</sub>	N <sub>186</sub>	N <sub>187</sub>	N <sub>188</sub>	N <sub>189</sub>	N <sub>190</sub>	N <sub>191</sub>	N <sub>192</sub>	N <sub>193</sub>	N <sub>194</sub>	N <sub>195</sub>	N <sub>196</sub>	N <sub>197</sub>	N <sub>198</sub>	N <sub>199</sub>	N <sub>200</sub>	N <sub>201</sub>	N <sub>202</sub>	N <sub>203</sub>	N <sub>204</sub>	N <sub>205</sub>	N <sub>206</sub>	N <sub>207</sub>	N <sub>208</sub>	N <sub>209</sub>	N <sub>210</sub>	N <sub>211</sub>	N <sub>212</sub>	N <sub>213</sub>	N <sub>214</sub>	N <sub>215</sub>	N <sub>216</sub>	N <sub>217</sub>	N <sub>218</sub>	N <sub>219</sub>	N <sub>220</sub>	N <sub>221</sub>	N <sub>222</sub>	N <sub>223</sub>	N <sub>224</sub>	N <sub>225</sub>	N <sub>226</sub>	N <sub>227</sub>	N <sub>228</sub>	N <sub>229</sub>	N <sub>230</sub>	N <sub>231</sub>	N <sub>232</sub>	N <sub>233</sub>	N <sub>234</sub>	N <sub>235</sub>	N <sub>236</sub>	N <sub>237</sub>	N <sub>238</sub>	N <sub>239</sub>	N <sub>240</sub>	N <sub>241</sub>	N <sub>242</sub>	N <sub>243</sub>	N <sub>244</sub>	N <sub>245</sub>	N <sub>246</sub>	N <sub>247</sub>	N <sub>248</sub>	N <sub>249</sub>	N <sub>250</sub>	N <sub>251</sub>	N <sub>252</sub>	N <sub>253</sub>	N <sub>254</sub>	N <sub>255</sub>	N <sub>256</sub>	N <sub>257</sub>	N <sub>258</sub>	N <sub>259</sub>	N <sub>260</sub>	N <sub>261</sub>	N <sub>262</sub>	N <sub>263</sub>	N <sub>264</sub>	N <sub>265</sub>	N <sub>266</sub>	N <sub>267</sub>	N <sub>268</sub>	N <sub>269</sub>	N <sub>270</sub>	N <sub>271</sub>	N <sub>272</sub>	N <sub>273</sub>	N <sub>274</sub>	N <sub>275</sub>	N <sub>276</sub>	N <sub>277</sub>	N <sub>278</sub>	N <sub>279</sub>	N <sub>280</sub>	N <sub>281</sub>	N <sub>282</sub>	N <sub>283</sub>	N <sub>284</sub>	N <sub>285</sub>	N <sub>286</sub>	N <sub>287</sub>	N <sub>288</sub>	N <sub>289</sub>	N <sub>290</sub>	N <sub>291</sub>	N <sub>292</sub>	N <sub>293</sub>	N <sub>294</sub>	N <sub>295</sub>	N <sub>296</sub>	N <sub>297</sub>	N <sub>298</sub>	N <sub>299</sub>	N <sub>300</sub>	N <sub>301</sub>	N <sub>302</sub>	N <sub>303</sub>	N <sub>304</sub>	N <sub>305</sub>	N <sub>306</sub>	N <sub>307</sub>	N <sub>308</sub>	N <sub>309</sub>	N <sub>310</sub>	N <sub>311</sub>	N <sub>312</sub>	N <sub>313</sub>	N <sub>314</sub>	N <sub>315</sub>	N <sub>316</sub>	N <sub>317</sub>	N <sub>318</sub>	N <sub>319</sub>	N <sub>320</sub>	N <sub>321</sub>	N <sub>322</sub>	N <sub>323</sub>	N <sub>324</sub>	N <sub>325</sub>	N <sub>326</sub>	N <sub>327</sub>	N <sub>328</sub>	N <sub>329</sub>	N <sub>330</sub>	N <sub>331</sub>	N <sub>332</sub>	N <sub>333</sub>	N <sub>334</sub>	N <sub>335</sub>	N <sub>336</sub>	N <sub>337</sub>	N <sub>338</sub>	N <sub>339</sub>	N <sub>340</sub>	N <sub>341</sub>	N <sub>342</sub>	N <sub>343</sub>	N <sub>344</sub>	N <sub>345</sub>	N <sub>346</sub>	N <sub>347</sub>	N <sub>348</sub>	N <sub>349</sub>	N <sub>350</sub>	N <sub>351</sub>	N <sub>352</sub>	N <sub>353</sub>	N <sub>354</sub>	N <sub>355</sub>	N <sub>356</sub>	N <sub>357</sub>	N <sub>358</sub>	N <sub>359</sub>	N <sub>360</sub>	N <sub>361</sub>	N <sub>362</sub>	N <sub>363</sub>	N <sub>364</sub>	N <sub>365</sub>	N <sub>366</sub>	N <sub>367</sub>	N <sub>368</sub>	N <sub>369</sub>	N <sub>370</sub>	N <sub>371</sub>	N <sub>372</sub>	N <sub>373</sub>	N <sub>374</sub>	N <sub>375</sub>	N <sub>376</sub>	N <sub>377</sub>	N <sub>378</sub>	N <sub>379</sub>	N <sub>380</sub>	N <sub>381</sub>	N <sub>382</sub>	N <sub>383</sub>	N <sub>384</sub>	N <sub>385</sub>	N <sub>386</sub>	N <sub>387</sub>	N <sub>388</sub>	N <sub>389</sub>	N <sub>390</sub>	N <sub>391</sub>	N <sub>392</sub>	N <sub>393</sub>	N <sub>394</sub>	N <sub>395</sub>	N <sub>396</sub>	N <sub>397</sub>	N <sub>398</sub>	N <sub>399</sub>	N <sub>400</sub>	N <sub>401</sub>	N <sub>402</sub>	N <sub>403</sub>	N <sub>404</sub>	N <sub>405</sub>	N <sub>406</sub>	N <sub>407</sub>	N <sub>408</sub>	N <sub>409</sub>	N <sub>410</sub>	N <sub>411</sub>	N <sub>412</sub>	N <sub>413</sub>	N <sub>414</sub>	N <sub>415</sub>	N <sub>416</sub>	N <sub>417</sub>	N <sub>418</sub>	N <sub>419</sub>	N <sub>420</sub>	N <sub>421</sub>	N <sub>422</sub>	N <sub>423</sub>	N <sub>424</sub>	N <sub>425</sub>	N <sub>426</sub>	N <sub>427</sub>	N <sub>428</sub>	N <sub>429</sub>	N <sub>430</sub>	N <sub>431</sub>	N <sub>432</sub>	N <sub>433</sub>	N <sub>434</sub>	N <sub>435</sub>	N <sub>436</sub>	N <sub>437</sub>	N <sub>438</sub>	N <sub>439</sub>	N <sub>440</sub>	N <sub>441</sub>	N <sub>442</sub>	N <sub>443</sub>	N <sub>444</sub>	N <sub>445</sub>	N <sub>446</sub>	N <sub>447</sub>	N <sub>448</sub>	N <sub>449</sub>	N <sub>450</sub>	N <sub>451</sub>	N <sub>452</sub>	N <sub>453</sub>	N <sub>454</sub>	N <sub>455</sub>	N <sub>456</sub>	N <sub>457</sub>	N <sub>458</sub>	N <sub>459</sub>	N <sub>460</sub>	N <sub>461</sub>	N <sub>462</sub>	N <sub>463</sub>	N <sub>464</sub>	N <sub>465</sub>	N <sub>466</sub>	N <sub>467</sub>	N <sub>468</sub>	N <sub>469</sub>	N <sub>470</sub>	N <sub>471</sub>	N <sub>472</sub>	N <sub>473</sub>	N <sub>474</sub>	N <sub>475</sub>	N <sub>476</sub>	N <sub>477</sub>	N <sub>478</sub>	N <sub>479</sub>	N <sub>480</sub>	N <sub>481</sub>	N <sub>482</sub>	N <sub>483</sub>	N <sub>484</sub>	N <sub>485</sub>	N <sub>486</sub>	N <sub>487</sub>	N <sub>488</sub>	N <sub>489</sub>	N <sub>490</sub>	N <sub>491</sub>	N <sub>492</sub>	N <sub>493</sub>	N <sub>494</sub>	N <sub>495</sub>	N <sub>496</sub>	N <sub>497</sub>	N <sub>498</sub>	N <sub>499</sub>	N <sub>500</sub>	N <sub>501</sub>	N <sub>502</sub>	N <sub>503</sub>	N <sub>504</sub>	N <sub>505</sub>	N <sub>506</sub>	N <sub>507</sub>	N <sub>508</sub>	N <sub>509</sub>	N <sub>510</sub>	N <sub>511</sub>	N <sub>512</sub>	N <sub>513</sub>	N <sub>514</sub>	N <sub>515</sub>	N <sub>516</sub>	N <sub>517</sub>	N <sub>518</sub>	N <sub>519</sub>	N <sub>520</sub>	N <sub>521</sub>	N <sub>522</sub>	N <sub>523</sub>	N <sub>524</sub>	N <sub>525</sub>	N <sub>526</sub>	N <sub>527</sub>	N <sub>528</sub>	N <sub>529</sub>	N <sub>530</sub>	N <sub>531</sub>	N <sub>532</sub>	N <sub>533</sub>	N <sub>534</sub>	N <sub>535</sub>	N <sub>536</sub>	N <sub>537</sub>	N <sub>538</sub>	N <sub>539</sub>	N <sub>540</sub>	N <sub>541</sub>	N <sub>542</sub>	N <sub>543</sub>	N <sub>544</sub>	N <sub>545</sub>	N <sub>546</sub>	N <sub>547</sub>	N <sub>548</sub>	N <sub>549</sub>	N <sub>550</sub>	N <sub>551</sub>	N <sub>552</sub>	N <sub>553</sub>	N <sub>554</sub>	N <sub>555</sub>	N <sub>556</sub>	N <sub>557</sub>	N <sub>558</sub>	N <sub>559</sub>	N <sub>560</sub>	N <sub>561</sub>	N <sub>562</sub>	N <sub>563</sub>	N <sub>564</sub>	N <sub>565</sub>	N <sub>566</sub>	N <sub>567</sub>	N <sub>568</sub>	N <sub>569</sub>	N <sub>570</sub>	N <sub>571</sub>	N <sub>572</sub>	N <sub>573</sub>	N <sub>574</sub>	N <sub>575</sub>	N <sub>576</sub>	N <sub>577</sub>	N <sub>578</sub>	N <sub>579</sub>	N <sub>580</sub>	N <sub>581</sub>	N <sub>582</sub>	N <sub>583</sub>	N <sub>584</sub>	N <sub>585</sub>	N <sub>586</sub>	N <sub>587</sub>	N <sub>588</sub>	N <sub>589</sub>	N <sub>590</sub>	N <sub>591</sub>	N <sub>592</sub>	N <sub>593</sub>	N <sub>594</sub>	N <sub>595</sub>	N <sub>596</sub>	N <sub>597</sub>	N <sub>598</sub>	N <sub>599</sub>	N <sub>600</sub>	N <sub>601</sub>	N <sub>602</sub>	N <sub>603</sub>	N <sub>604</sub>	N <sub>605</sub>	N <sub>606</sub>	N <sub>607</sub>	N <sub>608</sub>	N <sub>609</sub>	N <sub>610</sub>	N <sub>611</sub>	N <sub>612</sub>	N <sub>613</sub>	N <sub>614</sub>	N <sub>615</sub>	N <sub>616</sub>	N <sub>617</sub>	N <sub>618</sub>	N <sub>619</sub>	N <sub>620</sub>	N <sub>621</sub>	N <sub>622</sub>	N <sub>623</sub>	N <sub>624</sub>	N <sub>625</sub>	N <sub>626</sub>	N <sub>627</sub>	N <sub>628</sub>	N <sub>629</sub>	N <sub>630</sub>	N <sub>631</sub>	N <sub>632</sub>
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TABLE 11.—CHARACTERISTIC X-RAY EMISSION SPECTRA AND ABSORPTION LIMITS: ELEMENTARY SUBSTANCES

Substances which are mutually isotopic seem to have identical spectra (29, 70, 145); see also 82Pb in this table.

In each group of elements, the lines are arranged, as well as may be, in the order of decreasing wave-length ( $\lambda$ ); the wave-lengths of those lines which are out of place, with reference to this order, are in italics. An "x" indicates that the line probably occurs, but coincides with another line. Except as otherwise indicated, the line notation is Siegbahn's and the difference notation is Sommerfeld's (Table 2).

The wave-lengths of at least some of the lines of the lighter elements are influenced by the valence of the element and are modified by the nature of the element with which it is combined and by the material of the anticathode upon which it is spread.

Final data are not available; for preliminary work, see (113, 116, 117). For effect of chemical combination upon absorption limits see Table 12.

For relations connecting related lines, see p. 27; for methods for determining the subseries to which a line belongs, see (17, 142, 149, 183, 184). The excitation potential ( $V_0 = h\nu_0/e = hc/e\lambda_0$ ) may be computed from the subseries absorption limit ( $\lambda_0$ ):  $V_0\lambda_0 = 12\,344$  volt Å (absolute) = 12 339 Int. volt Å, if  $h$ ,  $c$ , and  $e$  have the I. C. T. accepted values (Vol. I, p. 17) ( $\log_{10} 12\,339 = 4.09128$ ).

(Literature references are given at the beginning of each section of the table, and at the end of the table are notes regarding the precision of the data, recomputations, etc., see p. 43.)

Tabular values are  $\lambda$ , unit =  $1\text{m}\text{\AA} = 0.001\text{\AA} = 10^{-11}\text{cm}$ .

A. Sources.—Absorption limit: 12Mg, 13Al, and 18A (72, 80); others (114). Emission: Non-diagram lines ( $\alpha'$  to  $\beta_z$ ) of 11Na, 12Mg, and 13Al (193, 194), all relative to  $\alpha_{1,2}$ ;  $\beta_1$  to  $\beta_z$  of 14Si (8), of 15P (120), of 16S (116), of 17Cl (117);  $\Delta\lambda_{\alpha_{2-1}}$  (7); others (142).

Lines		5B	6C	8O	9F	Lit.	Grating		
$\alpha_{1,2}$	$K-L_{21,22}$			23730	18300	(162, 163)	Crystal		
$\alpha_{1,2}$	$K-L_{21,22}$		45500	24800		(51)	Crystal		
$\alpha_{1,2}$	$K-L_{21,22}$		43960			(128)	Ruled		
$\alpha_{1,2}$	$K-L_{21,22}$		45800			(89)	Ruled		
$\alpha_{1,2}$	$K-L_{21,22}$		44900	23800		(160)	Ruled		
Lines		11Na	12Mg*	13Al*†	14Si*	15P†	16S	17Cl	18A
$\alpha_2$	$K-L_{21}$	11883.6	9867.75	8319.40	7109.17	6141.71	5363.75	4721.36	
$\alpha_1$	$K-L_{22}$						5360.90	4718.21	
$\alpha_2-\alpha_1$	$\Delta\lambda_{\alpha_2-\alpha_1}$			2.44	2.61	2.72	2.88	2.97	
$\alpha'_1$		11836.3	9825.3	8285.2	7083	$x$	5340.6	4702.5	
$\alpha_3$		11803.9	9800.0	8265.8	7063.8	6102.2	5329.37	4688	
$\alpha_4$		11785.9	9784.2	8250.1	7053.7	6095.0	5323.25	4684	
$\alpha_5$		11717.7	9729.4	8208.8	7014		5262.6(?)		
$\alpha_6$		11687.1	9704.4	8188.6	7003				
$\beta_3$		11702	9647	8042	6793.3	5820.4¶	5047¶	4406.0	
$\beta_1^{**}$		11592	9538	7965	6754.5	5792.1	5021.8	4394.2††	
$\beta_{1z}^{**}$						5788.2	5017.6	4393.3	
$\beta_z^{**}$						5779.6	5013.5	4390.6††	
	K-limit	11550	9499	7944	6739.3	5779.6	5013.5	4390.6††	
			9511.2	7947.0	6731.0	5767.4	5008.8††	4393.8††	3865.7

\* For 12Mg, 13Al, and 14Si, Wentzel (1923) points out the following:

\* For 12Mg, 13Al, and 14Si, Wentzel (192) points out the following relations between values of  $\Delta\lambda$ :  $(\alpha_5 - \alpha_4)_s = (\alpha_3 - \alpha_{1,2})_{s+1}$ ;  $(\alpha_3 - \alpha_{1,2})_s < (\alpha_5 - \alpha_4)_s < (\alpha_2 - \alpha_1)_{s+1}$ .

† For 13Al, lines  $\alpha_3$  and  $\alpha_4$  appear (6) to have nearly equal intensities if  $V_T = 2.90$  kv; hence, nearly equal values of  $V_0$ , both  $< 2.9$  kv; for K-limit  $V_0 = 1.55$  kv. At  $V_T = 3.10$ ,  $\alpha'_1$ ,  $\alpha_3$ , and  $\alpha_4$  are present; if they arise from double ionisation, both electrons must be removed simultaneously and by the same cathode particle (24).

‡ Normal lines refer to red P. For P on Al,  $\lambda_{\beta_{1z}}$  = 5785.4 for red P and 5784.5 for black P.

B. Sources.—Absorption limits: 21Sc (72, 80), 27Co and 28Ni (60), others (114). Emission: K-series  $\beta_1$  of 19K, 20Ca, 21Sc, 24Cr and 25Mn;  $\alpha_1$ ,  $\alpha_2$ , and  $\beta_1$  of 24Cr and 25Mn; all except  $\beta'''$ , of 26Fe, 27Co, and 28Ni (79); cf. (58); all  $\beta''$  and  $\beta'''$  (58); others (142). L,

Lines		19K	20Ca	21Sc	22Ti	23V	24Cr	25Mn
$\alpha_{1,2}$	$L_{12}-M_{32,33}$					24200	21530	19390
$\beta_1$	$L_{21}-M_{32}$						21190	19040
$\alpha_2$	$K-L_{21}$	3737.06	3354.95	3028.40	2746.81	2502.13	2288.907	2101.489
$\alpha_1$	$K-L_{22}$	3733.68	3351.69	3025.03	2743.17	2498.35	2285.033	2097.506
$\alpha_2-\alpha_1$	$\Delta\lambda_{\alpha_{2-1}}$	3.21	3.28					
$\alpha'_1$		3730	3349	3023				
$\alpha_3$		3711.0	3332.3					
$\alpha_4$		3708.8†	3330.0	3006	2726.9	2484.6	2273.3	2087.9
$\beta_1$	$K-M_{21,22}$	3446.80†	3091.1	2799.2	2515.1§	2285.3§	2085.7	
$\beta''$		3443.0†	3083.43	2773.94	2508.98	2279.72	2080.586	1906.195
$\beta_2$	$K-N_{21,22}$	3434.6	3079.7	2767.5	2500.7	2272.6		
$\beta'''$		3400.7	3069.1	2758.0	2493.7	2264.6	2066.71	1893.27
	K-limit	3431.0	3044.3	2742.5	2483.6	2257.7	2061.7	1888.8
			3064.3	2751.7	2491.2	2263.0	2066.3	1892.1

§ Non-diagram line. Measured by Hjalmar except as otherwise indicated.

|| Measured by Dolejssek. For 17Cl he also lists  $\alpha''$ ,  $\lambda = 4712$ .

¶ For  $\beta_1$ , Dolejssek gives  $\lambda = 4406.0$  for 15P,  $\lambda = 5044.7$  for 16S.

\*\* For 15P, 16S, and 17Cl,  $\lambda_{\beta_1}$  and  $\lambda_{\beta_2}$  are average values for various chemical compounds that give both lines,  $\lambda_{\beta_{1z}}$  is the average value for those compounds that give only one line. For 11Na, 12Mg, 13Al, and 14Si,  $\lambda_{\beta_z}$  is for the pure element,  $\lambda_{\beta_1}$  is for oxide or other compound.

†† For CaCl<sub>2</sub>,  $\lambda_{\beta_1} = 4394.7$ ,  $\lambda_{\beta_2} = 4388.4$ .

‡‡ Hjalmar lists for 16S  $\beta_1$  (?),  $\lambda = 5012.7$ ; and for 17Cl  $\beta''$ ,  $\lambda = 4390.8$ .



TABLE 11B.—(Continued)

Lines		26Fe†	27Co	28Ni	Lines		26Fe†	27Co	28Ni
$l$	$L_{21}-M_{11}$	20120	18200	16550	$\alpha_{3,4}^*$		1923.3	1777.4	1647.6
$\eta$	$L_{21}-M_{11}$	19650	17770	16170	$\beta_3$		1756.46	1620.11	1499.10
$\alpha_{1,2}$	$L_{21}-M_{32,33}$	17580	15940	14528	$\beta_1$	$K-M_{21,22}$	1753.013	1617.436	1497.045
$\beta_1$	$L_{21}-M_{32}$	17220	15620	14235	$\beta_2$	$K-N_{21,22}$	1740.80	1605.62	1485.61
$\beta_{3,4}$	$L_{11}-M_{21,22}$	15610		13140	$\beta'''$		1737.1		
$\alpha_2$	$K-L_{21}$	1936.012	1789.187	1658.353		$K$ -limit	1740.5	1602.3	1489.5
$\alpha_1$	$K-L_{22}$	1932.076	1785.287	1654.503					

\* Non-diagram lines. Measured by Dolejšek, unless otherwise indicated.

† Hjalmar also lists for 19K,  $\lambda\alpha' = 3712.7$ ,  $\lambda\alpha_{3,4} = 3708.83$ .‡ Lundquist (120) finds for 19K,  $K\beta_1 = 3446.99$ ,  $K\beta'' = 3443.09$ .

§ Non-diagram lines. Measured by Hjalmar.

|| For 25Mn,  $\lambda\beta_2 = 1910.50$  (79).¶ The  $K\alpha$ -lines of Fe are unresolved multiplets.

C. Sources.—Absorption limit: 36Kr (23); others (60). Emission:  $K$ -series of 31Ga (167);  $K\alpha_2$ ,  $K\beta_2$ , and  $K\alpha_{3,4}$  of 29Cu, and  $K\alpha_{1,4}$  of 30Zn (142); others of  $K$ -series (105, 108, 109);  $L$ -series (165).

Lines		29Cu	30Zn	31Ga	32Ge	33As	34Se	35Br	36Kr
$l$	$L_{21}-M_{11}$	15190	13950	12890	11920	11047	10271	9563	
$\eta$	$L_{21}-M_{11}$	14830	13610	12560	11585	10710	9939	9234	
$\alpha_{1,2}$	$L_{21}-M_{32,33}$	13308	12224	11270	10414	9650	8971	8357	
$\alpha'$		13240	12191	11238	10378	9616	8939	8326	
$\alpha''$		13172	12150	11196	10341	9581	8903	8297	
$\beta_1$	$L_{21}-M_{32}$	13029	11958	11006	10152	9394	8717	8108	
$\beta'$		12990	11934	10986	10131	9372	8698	8086	
$\beta''$		12960	11893	10951	10102	9346	8671	8065	
$\beta_{3,4}$	$L_{11}-M_{21,22}$	12100	11160			8911			
$\alpha_2$	$K-L_{21}$	1541.26	1435.87	1340.87	1255.21	1177.40	1106.43	1041.60	
$\alpha_1$	$K-L_{22}$	1537.39	1432.06	1337.14	1251.30	1173.43	1102.42	1037.56	
$\alpha_{3,4}^\dagger$		1530.7	1428.8						
$\beta_{3,1}$	$K-M_{21,22}$	1389.27	1292.60	1205.20	1126.74	1055.18	990.25	930.84	
$\beta_2$	$K-N_{21,22}$	1378.0	1280.97		1114.62	1042.93	997.90	918.26	
	$K$ -limit	1379.0	1296.7	1190.6	1115.0	1043.8	979.3	918.2	864.8

\* Also 11224. † Non-diagram lines. Measured by Dolejšek.

D. Sources.—Absorption limit:  $K$ -series (60),  $L$ -series (73). Emission:  $K$ -series 42Mo (106), 45Rh (78), 46Pd (except  $\beta_4$ ) (96), others (105, 108);  $L$ -series  $\beta_2$ ,  $\beta_3$ ,  $\gamma_1$ , and  $\gamma_{2,3}$  (79), others (142).

Lines		37Rb	38Sr	39Yt	40Zr	41Cb	42Mo*	44Ru	45Rh
$l$	$L_{21}-M_{11}$		7821		6898	6509			5207.0
$\eta$	$L_{21}-M_{11}$	8029.0	7505		6593.1	6195	5835		4911.2
$\alpha_2$	$L_{21}-M_{32}$					5717	5400	4843.67	4595.56
$\alpha_1$	$L_{21}-M_{33}$	7302.7	6847.8	6434.9	6055.9	5711.3	5394.3	4835.67	4587.78
$\alpha_3^\dagger$		7272.7	6818.3	6406.5	6027.2	5688.6	5372.1	4818	4572
$\beta_1$	$L_{21}-M_{32}$	7060.4	6609.2	6198.4	5822.2	5479.6	5165.8	4611.00	4364.00
$\beta_6$	$L_{21}-N_{11}$	6967.5	6503.0		5693.5	5346.1		4476.4	4230.1
$\beta_4$	$L_{11}-M_{21}$	6802.8	6385.5	6001.9	5652.7	5331.4	5035.8	4512.6	4277.8
$\beta_3$	$L_{11}-M_{22}$	6769.9	6349.9	5967.8	5618.2	5295.9	5000.2	4476.4	4241.3
$\beta_2$	$L_{21}-N_{11,22}$				5573.4	5225.3	4909.2	4361.9	4122.1
	$L_{21}$ -limit							4360.4	4121.2
$\beta_2^\dagger$ ( $\beta_{11}$ )								4323.4	4087.8
$\beta_2^\dagger$ ( $\beta_{12}$ )						5169	4862.6	4309.0	4076.6
$\gamma_6$	$L_{21}-N_{11}$	6738.6	6278.8		5481.0		4819.0	4276.6	4035.2
$\gamma_1$	$L_{21}-N_{22}$				5373.0	5024.1	4711.1	4172.82	3935.7
$\gamma_1^\dagger$ ( $\gamma_7$ )	$L_{21}$ -limit							4169.3	3934.0
								4128	3894
$\gamma_{2,3}$	$L_{11}-N_{21,22}$	6028.2	5629.4		4941.2	4639	4361.3	3887.9	3677.0
$\gamma_{2,3}^\dagger$					4895	4597	4323		3647
	$L_{11}$ -limit								3618.6
$\alpha_2$	$K-L_{21}$	927.72	877.54	831.18	788.50	748.82	712.105†	646.15	616.371
$\alpha_1$	$K-L_{22}$	923.60	873.37	827.00	784.29	744.57	707.831†	641.81	612.023
$\beta_1$	$K-M_{21}$						631.543		545.093
$\beta_1$	$K-M_{22}$	827.02	781.51	739.32	700.48	664.49	630.978†	571.43	544.491



TABLE 11D.—(Continued)

Lines		37Rb	38Sr	39Yt	40Zr	41Cb	42Mo*	44Ru	45Rh
$\beta_2$	$K-N_{21,22}$ .....	814.84	769.17	726.63	688.35	652.55	619.698	560.48	533.957
$\beta_4$	$K-O_{21,22}$ .....						618.25		
	$K$ -limit .....	814.6	769.9	725.7	687.4	650.5	618.2	558.6	533.2

Lines		46Pd	Lines		46Pd	Lines		46Pd
$l$	$L_{22}-M_{11}$ .....	4939.6	$\beta_2$	$L_{22}-N_{32,33}$ .....	3900.7		$L_{11}$ -limit .....	3420.6
$\eta$	$L_{21}-M_{11}$ .....	4650.2		$L_{22}$ -limit .....	3900.5	$\alpha_2$	$K-L_{21}$ .....	588.632
$\alpha_2$	$L_{22}-M_{32}$ .....	4366.60	$\beta_2' \dagger (\beta_{11})$		3868.8	$\alpha_1$	$K-L_{22}$ .....	534.266
$\alpha_1$	$L_{22}-M_{33}$ .....	4358.50	$\beta_2'' \dagger (\beta_{12})$		3857.4	$\beta_3$	$K-M_{21}$ .....	520.093
$\alpha_2 \dagger$		4344	$\gamma_5$	$L_{21}-N_{11}$ .....	3811.6	$\beta_1$	$K-M_{22}$ .....	519.474
$\beta_1$	$L_{21}-M_{32}$ .....	4137.30	$\gamma_1$	$L_{21}-N_{32}$ .....	3716.36	$\beta_2$	$K-N_{21,22}$ .....	509.181
$\beta_4$	$L_{11}-M_{21}$ .....	4062.3		$L_{21}$ -limit .....	3715.2	$\beta_4$	$K-O_{21,22}$ .....	507.90§
$\beta_3$	$L_{11}-M_{22}$ .....	4025.7	$\gamma_1' \dagger (\gamma_7)$		3678		$K$ -limit .....	507.70
$\beta_5$	$L_{22}-N_{11}$ .....	4007.0	$\gamma_{2,3}$	$L_{11}-N_{21,22}$ .....	3480.9			

\* For 42Mo, non-diagram line  $L\alpha_3$  has 6 components, usually unresolved; none of them are present if  $V = 3$  kv, but the three nearest to  $L\alpha_1$  are present if  $V = 4$  kv; the others appear only at higher voltages (143). The normal lines  $L\alpha_1$  and  $L\alpha_2$  are excited at  $V = 2.9$  kv.

† Non-diagram lines listed by Siegbahn.

‡ For Mo, Davis and Purks (53.2) find satellites on the long-wave sides of  $\alpha_2$ ,  $\alpha_1$ , and  $\beta_1$ , the separations being 0.096, 0.085, and 0.17mÅ, respectively; they call them  $\alpha_2'$ ,  $\alpha_1'$ , and  $\beta_1'$ .

§ Of doubtful origin; value from (109).

E. Sources (except as otherwise indicated).—Absorption limit:  $K$ -limit, 54Xe (23), others (60);  $L$ -limit, 54Xe (110), others (27, 73). Emission:  $K$ -series, 47Ag (96), 53I (33), others (33, 96, 105, 108);  $L$ -series  $\beta_2$  and  $\beta_2'$  (79), others (142).

Lines		47Ag	48Cd	49In	50Sn	51Sb	52Te	53I	54Xe
$l$	$L_{22}-M_{11}$ .....	4697.6	4471.3	4259.3	4063.3	3880.3	3710.1		
$\eta$	$L_{21}-M_{11}$ .....	4410.1	4187.5	3976.1	3781.8	3599.6			
$\alpha_2$	$L_{22}-M_{32}$ .....	4153.82	3956.36	3772.42	3601.08	3440.75	3291.03	3150.87	
$\alpha_1$	$L_{22}-M_{33}$ .....	4145.64	3947.82	3763.67	3592.18	3431.77	3281.92	3141.66	
$\alpha_3^*$		4131.70	3933	3749.91					
$\beta_1$	$L_{21}-M_{32}$ .....	3926.64	3730.08	3547.83	3377.92	3218.36	3069.97	2930.93	
$\beta_4$	$L_{11}-M_{21}$ .....	3861.1	3674.25	3499.0	3336.3	3184.3	3040.0	2906	
$\beta_3$	$L_{11}-M_{22}$ .....	3824.45	3636.42	3461.9	3298.9	3145.14	3001.3	2867	
$\beta_5$	$L_{22}-N_{11}$ .....	3799.4	3607.3	3428.0	3262.2	3107.8	2964.4		
$\beta_2$	$L_{22}-N_{32,33}$ .....	3693.83	3506.4	3331.2	3167.9	3016.6†	2876.1	2746.08	
$\beta_7$	$L_{22}-O_{11}$ .....			3317	3149				
	$L_{22}$ -limit .....	3690.8	3496.3	3315.5	3149.3	2990.7	2845.7	2713.9	2587.5†
$\beta_2' \dagger (\beta_{11})$		3663.5	3478.7	3304.0	3142.6	2993.4			
$\beta_2'' \dagger (\beta_{12})$		3653.6	3470.7	3295.9	3134.7	2985.8†			
$\beta_{10}^*$		3630		3265.8	3114.4	2972.5			
$\beta_9^*$		3620		3259.8	3108.1	2965.8			
$\gamma_5$	$L_{21}-N_{11}$ .....	3607.3	3418.1	3241.8	3077.4	2925.6	2783.1		
$\gamma_1$	$L_{21}-N_{32}$ .....	3514.85	3328.0	3155.29	2994.93	2845.07†	2706.47	2577.48	
	$L_{21}$ -limit .....	3506.7	3319.0	3139.5	2972.3	2821.9	2679.3	2547.5	2425.3†
$\gamma_1' \dagger (\gamma_7)$		3480	3296	3125	2968.5				
$\gamma_{2,3}$	$L_{11}-N_{21,22}$ .....	3299.7	3131.6	2973.6	2827.3	2688.9	2564.9		
$\gamma_{2,3}^*$		3270							
$\gamma_4$	$L_{11}-O_{21,22}$ .....			2919.1	2771.3	2633.6	2505.7		
	$L_{11}$ -limit .....	3247.4	3077.3	2919.4	2769.6	2631.7	2503.9	2383.9	2272.4†
$\alpha_2$	$K-L_{21}$ .....	562.669	538.29	515.46	493.96	473.86	454.91	436.94	
$\alpha_1$	$K-L_{22}$ .....	553.277	533.86	511.03	489.48	469.31	450.37	432.43	
$\beta_3$	$K-M_{21}$ .....	496.647	474.97	454.42	435.06	416.23	399.26	383.92	
$\beta_1$	$K-M_{22}$ .....	496.009	474.29	453.72	434.40		390.37	383.15	
$\beta_2$	$K-N_{21,22}$ .....	486.030	464.38	444.09	424.85	407.10	390.37	374.61	
	$K$ -limit .....	485.2	463.4	443.6	424.3	406.6	389.7	373.8	538.8

\* Non-diagram lines listed by Siegbahn (142).

† Dauvillier (5, 47) lists for 51Sb  $\beta_2' \lambda = 3011.7$ ,  $\beta_2 (\lambda_{11}-M_{32}) \lambda = 2989$ ,  $\beta_4 (\lambda_{11}-M_{21}) \lambda = 2985.5$  (corresponding, respectively, to Siegbahn's  $\beta_2$ ,  $\beta_{10}$ ,  $\beta_3$ ), and  $\gamma_{10} \lambda = 2840$ .

‡ These  $L$ -limits show strong absorption lines like the electropositive elements and unlike I<sup>-</sup> and Br<sup>-</sup>; they lie on the extrapolated curve for Ag to I, but not on that from Cs to Nd (110).



TABLE 11.—(Continued)

*F. Sources* (except as otherwise noted).—Absorption limit: *K*-limits, 55Cs and 56Ba (<sup>60</sup>), others (<sup>24</sup>); *L*-limits, 55Cs *L*<sub>11</sub> (<sup>118</sup>), 57La and 58Ce (<sup>41</sup>), others (<sup>127</sup>). Emission: *K*-series (<sup>32</sup>, <sup>33</sup>); *cf.* (<sup>109</sup>); *L*-series, 56Ba, all  $\beta_5$ , all  $\gamma_6$  (*L*<sub>21</sub>-*O*<sub>22</sub>), and  $\gamma_4$  63Eu (<sup>5</sup>, <sup>48</sup>), others (<sup>142</sup>).

Lines		55Cs	56Ba	57La	58Ce	59Pr	60Nd	62Sa	63Eu
<i>l</i>	<i>L</i> <sub>22</sub> - <i>M</i> <sub>11</sub> .....		3128.7	3000		2778.1	2670.3	2477.0	2390.3
$\eta$	<i>L</i> <sub>21</sub> - <i>M</i> <sub>11</sub> .....	2983.3	2857.1	2734	2614.7	2507	2404.2	2214.5	
$\alpha_2$	<i>L</i> <sub>22</sub> - <i>M</i> <sub>32</sub> .....	2895.60	2779.02	2668.93	2565.11	2467.63	2375.63	2205.68	2127.33
$\alpha_1$	<i>L</i> <sub>22</sub> - <i>M</i> <sub>33</sub> .....	2886.10	2769.64	2659.68	2556.00	2457.70	2365.31	2195.01	2116.33
$\alpha_3^*$			2755.4†					2184.6	
$\beta_{11}^*$	<i>L</i> <sub>11</sub> - <i>M</i> <sub>11</sub> .....		2631.5						
$\beta_1$	<i>L</i> <sub>21</sub> - <i>M</i> <sub>32</sub> .....	2677.84	2562.24	2453.30	2351.00	2253.90	2162.21	1993.57	1916.31
$\beta_4$	<i>L</i> <sub>11</sub> - <i>M</i> <sub>21</sub> .....	2660.5	2549.8	2443.8	2344.2	2250.1	2162.2	1996.4	1922.1
$\beta_{12}^*$	<i>L</i> <sub>21</sub> - <i>M</i> <sub>32</sub> .....						2154.8	1987.6†	1908.1†
$\beta_2$	<i>L</i> <sub>11</sub> - <i>M</i> <sub>22</sub> .....	2622.93	2511.0	2405.3	2305.9	2212.4	2122.2	1958.0	1882.7
$\beta_6$	<i>L</i> <sub>22</sub> - <i>N</i> <sub>11</sub> .....	2587.5	2477.2	2373.9	2276.9	2185.9	2099.3	1942.2	1870.5
$\beta_{14}^{\S}$					2212.1	2122.0	2038.8	1885.1	1781.4
$\beta_2$	<i>L</i> <sub>22</sub> - <i>N</i> <sub>32,33</sub> .....	2506.4	2399.3†	2298.0	2204.1	2114.8	2031.4	1878.1	1808.2
$\beta_{11,12}^{\S}$		2483	2381.7						
$\beta_9^*$	<i>L</i> <sub>11</sub> - <i>M</i> <sub>32</sub> .....	2381.3¶						1866.2¶	1794.0¶
$\beta_{10}^{\S}$				2285	2191.6	2102.5	2019.3	1865.7	1796
$\beta_9^{\S}$		2473	2371.2	2277	2184.0	2095.8	2011.7	1858.1	1788
$\beta_8^*$	<i>L</i> <sub>11</sub> - <i>M</i> <sub>32</sub> .....		2375.5		2184.4		2013.8	1858.9	1786.0
$\beta_7$	<i>L</i> <sub>22</sub> - <i>O</i> <sub>11</sub> .....	2480	2375.6	2270	2176.3	2087.4	2004.3	1852.3	1784
$\beta_6$	<i>L</i> <sub>22</sub> - <i>O</i> <sub>32,33</sub> .....		2359.5		2164.0			1843.7	1773.4
	<i>L</i> <sub>22</sub> -limit.....	2467.4	2356.8	2253.7	2159.7	2072.8	1990.7	1840.8	1771.7
$\beta_{10}^*$			2351.1		2153.1			1834.0	1764.7
$\gamma_8$	<i>L</i> <sub>21</sub> - <i>N</i> <sub>11</sub> .....	2411.1	2302.3	2200.8	2105.6	2016.1	1931.3	1775.1	1705
$\gamma_1^*$					2051.1		1879.3	1728.7	1658.9
$\gamma_9^{\S}$					2051	1962.2	1880.4	1728.5	1659.3
$\gamma_1$	<i>L</i> <sub>21</sub> - <i>N</i> <sub>32</sub> .....	2342.52	2236.60†	2137.20	2044.33	1956.81	1873.83	1723.09	1654.3
$\gamma_{10}^*$			2218.6		2028.8		1860.0	1711.3	1642.2
$\gamma_8$	<i>L</i> <sub>21</sub> - <i>O</i> <sub>11</sub> .....		2218		2019	1932.2			1629
$\gamma_7^{\S}$			2218		2029	1942.2	1859		1644
$\gamma_6^*$	<i>L</i> <sub>21</sub> - <i>N</i> <sub>42</sub> .....		2211.2		2019.6		1851.4	1701.9	1633.4
$\gamma_6$	<i>L</i> <sub>21</sub> - <i>O</i> <sub>32</sub> .....		2201.6		2009.1		1842.6	1692.6	1624.1
	<i>L</i> <sub>21</sub> -limit.....	2307.5	2199.3	2098.9	2006.7	1920.1	1839.1	1699.1	1622.8
$\gamma_7^*$			2143.8					1664.4	1598.6
$\gamma_{10}^{\S}$		2236.9	2140.2	2048.1	1962.3	1881.1			
$\gamma_3^*$			2134.2		1956.1			1656.0	1591.9
$\gamma_2$	<i>L</i> <sub>11</sub> - <i>N</i> <sub>31</sub> .....	2232.2	2134.0	2041.6	1955.9	1875.0	1797.4	1655.9	1593.9
$\gamma_2$	<i>L</i> <sub>11</sub> - <i>N</i> <sub>22</sub> .....	2227.0	2129.5	2036.5	1950.9	1869.9	1792.5	1651.7	1587.7
$\gamma_9^*$	<i>L</i> <sub>11</sub> - <i>N</i> <sub>31</sub> .....		2098.9		1922.5			1626.1	1561.9
$\gamma_4$	<i>L</i> <sub>11</sub> - <i>O</i> <sub>21,22</sub> .....	2169.1	2071.5†	1978.7	1895.2	1815.3	1740.8	1603.3	1541.0
	<i>L</i> <sub>11</sub> -limit.....	2160.5	2062.0	1968.9	1885.6	1807.1	1731.7	1595.4	1533.3
$\alpha_2$	<i>K</i> - <i>L</i> <sub>21</sub> .....	403.98	388.91	374.60	360.97	348.05	335.96	313.20	302.69
$\alpha_1$	<i>K</i> - <i>L</i> <sub>22</sub> .....	399.48	384.31	369.96	356.37	343.40	331.31	308.54	297.99
$\beta_2$	<i>K</i> - <i>M</i> <sub>21</sub> .....	354.36	340.89	328.09	315.72	304.39	293.51	273.25	263.86
$\beta_1$	<i>K</i> - <i>M</i> <sub>22</sub> .....	353.62	340.22	327.26	315.01	303.60	292.75	272.50	263.07
$\beta_2$	<i>K</i> - <i>N</i> <sub>21,22</sub> .....	345.16	332.22	319.66	307.70	296.25	285.73	265.75	256.45
	<i>K</i> -limit.....	344.5	330.8	318.6	306.5	295.1	284.6	264.4	254.8

\* Non-diagram lines listed by Dauvillier (<sup>5</sup>, <sup>47</sup>); if a difference notation is given, it is to be regarded as tentative. In this table, Dauvillier's  $\beta_7$  and  $\beta_7'$  are entered as  $\beta_7'$  and  $\beta_7$ , respectively. His  $\beta_1'$ ,  $\beta_2$ ,  $\beta_3$  are, respectively, the same as Siegbahn's  $\beta_2$ ,  $\beta_3$ ,  $\beta_{10}$ .

† For 56Ba, Dauvillier (<sup>5</sup>, <sup>47</sup>) lists the following non-diagram lines:  $\alpha_4\lambda = 2732.7$ ,  $\beta_2'\lambda = 2395.4$ ,  $\gamma_1'\lambda = 2232.4$ ,  $\gamma_4'\lambda = 2067.5$ .

‡ Siegbahn (<sup>142</sup>) gives for  $\beta_{12}\lambda_{\text{Ba}} = 1987.1$ ,  $\lambda_{\text{Eu}} = 1909.2$ .

§ Non-diagram lines listed by Siegbahn (<sup>142</sup>).

|| Dauvillier (<sup>5</sup>, <sup>47</sup>) gives for  $\beta_{12}\lambda_{\text{Ce}} = 2212.4$ ,  $\lambda_{\text{Nd}} = 2039.5$ ,  $\lambda_{\text{Sm}} = 1886.0$ ,  $\lambda_{\text{Eu}} = 1813.9$ .

¶ Also called  $\beta_2''$  by the same author.



TABLE 11.—(Continued)

G. Sources (except as otherwise noted).—Absorption limit: K-limits (24), L-limits, 65Tb ( $L_{11}$ ) and 67Ho (127), 65Tb ( $L_{21}$ - $L_{22}$ ) and 70Yb (74), others (41). Emission: K-series 67Ho (109), others (32, 33); cf. (109). L-series, 69Tu (37),  $\beta_5$  ( $L_{21}$ - $O_{22}$ , 23), and  $\gamma_8$  ( $L_{21}$ - $O_{22}$ ) (5, 48), others (142); M-series (83).

Lines	64Gd	65Tb	66Dy	67Ho	68Er	69Tu	70Yb	71Lu
$\alpha_1$	$M_{31}$ - $N_{44}$ .....							7820
$\alpha'^*$								7803
$\alpha'^*$							8111	7787
$\beta$	$M_{32}$ - $N_{43}$ .....						8090	7582
$\beta'^*$				8919				7560
$\beta'^*$							7870	7852
$\gamma$	$M_{22}$ - $N_{32,33}$ .....							6780
$l$	$L_{22}$ - $M_{11}$ .....	2307.1	2229.0	2154.0	2082.1	2015.1		1890.0
$\alpha_2$	$L_{22}$ - $M_{22}$ .....	2052.62	1982.31	1915.64	1852.06	1791.40	1733.9	1678.9
$\alpha_1$	$L_{22}$ - $M_{33}$ .....	2041.93	1971.49	1904.60	1840.98	1780.40	1722.8	1667.79
$\eta$	$L_{21}$ - $M_{11}$ .....			1892.2	1822.0	1754.8	1692.3	1631.0
$\beta_4$	$L_{11}$ - $M_{21}$ .....	1849.3	1781.4	1716.7	1655.3	1596.4	1541.2	1488.2
$\beta_1$	$L_{21}$ - $M_{32}$ .....	1842.46	1772.68	1706.58	1643.52	1583.44	1526.8	1472.5
$\beta_{13}\dagger$		1835.5	1765.5	1699.2	1635.5	1575.6		1420.7
$\beta_3$	$L_{11}$ - $M_{22}$ .....	1810.9	1742.5	1677.7	1616.0	1557.9	1502.3	1449.4
$\beta_6$	$L_{22}$ - $N_{11}$ .....	1803.1	1737.5	1677.7	1618.8	1563.6	1511.5	1462.7
$\beta_{14}\dagger$		1748.1†	1685.1	1625.1	1567	1512		1414.3
$\beta_2$	$L_{22}$ - $N_{32,33}$ .....	1741.9	1679.0	1619.8	1563.7	1510.6	1460.2	1412.8†
$\beta_2\beta_2''\dagger$ ( $\beta_{11,12}$ )					1501.4			1367.2†
$\beta_9\ddagger$	$L_{11}$ - $M_{32}$ .....	1729.3						1359
$\beta_{10}\dagger$		1728.1	1664					1339.8
$\beta_9\ddagger$								1339.8
$\beta_8\ddagger$	$L_{11}$ - $M_{33}$ .....	1720.0				1482.3		1333.0
$\beta_7\ddagger$	$L_{22}$ - $N_{43,44}$ .....							1333.0
$\beta_7$	$L_{22}$ - $O_{11}$ .....	1719.6	1655.8	1595.7		1489.2		1346.6
$\beta_9\ddagger$						1482.3		1345.9
$\beta_5$	$L_{22}$ - $O_{22,23}$ .....	1709.3						1333.0
	$L_{22}$ -limit.....	1706.2†	1644.2	1587.0	1532.2	1479.6	1429.9	1382.64
$\gamma_6$	$L_{21}$ - $N_{11}$ .....	1637.6	1574.2	1515.2	1459	1403	1352.3	1303.0
$\gamma_9\ddagger$		1593.6†	1531.4		1416			1256
$\gamma_1$	$L_{21}$ - $N_{32}$ .....	1588.63	1526.6	1469.7	1414.2	1362.3	1312.7	1264.8
$\gamma_{10}\ddagger$		1578.9						1220.3
$\gamma_6\ddagger$	$L_{21}$ - $N_{43}$ .....	1569.5						1256.8
$\gamma_6$	$L_{21}$ - $O_{22}$ .....	1561.5						1248.3
	$L_{21}$ -limit.....	1558.7	1499.4	1441.4	1386.9	1334.9	1284.9	1240.5
$\gamma_2$	$L_{11}$ - $N_{21}$ .....	1531.0†	1473.8	1420.3	1367.7	1318.4	1271.2	1238.14
$\gamma_2$	$L_{11}$ - $N_{22}$ .....	1525.9	1468.3	1413.9	1361.3	1311.8	1265.3	1225.6
$\gamma_9\ddagger$	$L_{11}$ - $N_{33}$ .....	1538.3						1219.8
$\gamma_4$	$L_{11}$ - $O_{21,22}$ .....	1481.8	1423.9	1371.4	1319.7	1273.2	1226.4	1201.6
	$L_{11}$ -limit.....	1474.0	1417.0	1364.8	1314.6	1266.0	1219.6	1182.0
$\alpha_2$	$K$ - $L_{21}$ .....	292.41	282.94	273.64	264.99	256.72	248.61	1176.4
$\alpha_1$	$K$ - $L_{22}$ .....	287.73	278.19	268.87	260.30	251.99	243.87	1136.2
$\beta_3$	$K$ - $M_{21}$ .....	254.71	246.29	237.87		223.00	215.58	240.99
$\beta_1$	$K$ - $M_{22}$ .....	253.94	245.51	237.10		222.15	214.87	236.22
$\beta_2$	$K$ - $N_{21,22}$ .....	247.62	239.12	231.28		216.71		209.16
	$K$ -limit.....	246.2	237.6	230.1	221.8	215.8	208.5	203.22
							201.6	196.49
								195.1

\* Satellites of diagram lines; not resolved in any photograph (83).  $M_{\alpha}$  and  $M_{\beta}$  are unresolved multiplets; for details of structure, see (166).

† Other non-diagram lines listed by Dauvillier (5, 47) are: For 64Gd,  $\beta_{14}\lambda = 1748.7$ ,  $\beta_{10}\lambda = 1703.3$ ,  $\gamma_{11}\lambda = 1594.6$ ,  $\gamma_{12}\lambda = 1538.3$ ; for 70Yb,  $\beta_{11}'\lambda = 1405.9$ ; for 71Lu,  $\alpha_{12}\lambda = 1612.2$ ,  $\beta_{12}'\lambda = 1368.9$ ,  $\beta_{12}''\lambda = 1357.9$ .

‡ Non-diagram lines listed by Siegbahn (142).

§ Non-diagram lines listed by Dauvillier (5, 47); if a difference notation is given, it is to be regarded as tentative. In this table, Dauvillier's  $\beta_7$  and  $\beta_7'$  are entered as  $\beta_7'$  and  $\beta_7$ , respectively. His  $\beta_2'$ ,  $\beta_3$ ,  $\beta_5$  are, respectively, same as Siegbahn's  $\beta_2$ ,  $\beta_3$ ,  $\beta_{10}$ .



TABLE 11.—(Continued)

*H. Sources* (except as otherwise indicated).—Absorption limit: *K*-limits, 72Hf and 73Ta (24), 74W (see Table 7), others (59); *L*-limits, 72Hf (41), 73Ta and 74W (127), others (63, 66); *M*-limits, 74W (197) and 76Os, 77Ir, and 78Pt (136). Emission: *K*-series, 72Hf (33); cf. (109), others (38); *L*-series in ( ) (81), 72Hf (37), 73Ta stronger (188), others (36), corrected, 76Os ( $\eta$ ,  $\beta_2$ ,  $\beta_3$ ,  $\beta_4$ ,  $\beta_5$ ,  $\beta_6$ ,  $\beta_7$ ,  $\gamma_5$ ,  $\gamma_6$ ), 77Ir ( $\eta$ ,  $\beta_1$ ,  $\gamma_4$ ,  $\gamma_5$ ), and 79Au ( $\beta_2$ ,  $L_{21}$ - $P_{11}$ ,  $L_{22}$ - $P_{11}$ ) (47); others (142); *M*-series, 72Hf (37), 74W (161), others (83).

Lines		72Hf	73Ta	74W*	76Os	77Ir*	78Pt*	79Au*
$\alpha_1$ $\alpha''\dagger$	$M_{22}$ - $N_{22}$ .....					8012		$x$
	$M_{22}$ - $N_{11}$ .....			7349	6882	6663		6264
	$M_{22}$ - $N_{44}$ .....	7521	7238	6963	6481	6250	6041	5831
$\beta$ $\beta''\dagger$				6952	6459	6223	6026	5812
	$M_{22}$ - $O_{21,22}$ .....			6750				
	$M_{22}$ - $N_{44}$ .....	7286	7001	6733	6256	6030	5820	5619
$\gamma$ $\gamma'$				6726	6233	6011	5797	
	$M_{22}$ -limit.....			6708	6194	5961	5736	
	$M_{22}$ -limit.....			6475	5975	5754	5541	
$\gamma$ $\gamma'$	$M_{21}$ - $N_{11}$ .....			6271	5802			
	$M_{22}$ - $N_{32}$ .....		} 6301	6123	} 5672	5484	5303	5131
	$M_{22}$ - $N_{32}$ .....			6083				
$\gamma$ $\gamma'$				6066				
	$M_{22}$ - $O_{11}$ .....			5607				
	$M_{22}$ -limit.....			5416	5027	4851	4674	
$\gamma$ $\gamma'$	$M_{21}$ - $N_{32}$ .....			5365	4949	4768	$x$	$x$
	$M_{11}$ - $N_{22}$ .....			5157	4779	4548	4407	4230
	$M_{21}$ -limit.....			4800	4412	4270	3738	
$\gamma$ $\gamma'$	$M_{11}$ - $O_{21,22}$ .....			4433				
	$M_{11}$ -limit.....			4365	4037			
	$L_{22}$ - $M_{11}$ .....	1777.4	1724.2	1675.05 (1675.0)			1497.23	1456.54
$\gamma$ $\gamma'$				1621.6		1490.0	1449.0	1410.0
				1561		1429.5		1348.1
	$L_{22}$ - $M_{12}$ .....	1577.04	1529.8	1484.52 (1484.38)	1398.2	1359.39 (1359.8)	1321.21 (1321.55)	1284.89 (1285.02)
$\alpha_1$ $\alpha_2$	$L_{22}$ - $M_{32}$ .....	1566.07	1518.85	1473.48 (1473.36)	1388.16	1348.34 (1348.47)	1310.08 (1310.33)	1273.55 (1273.77)
				1514.3	1383.2	1343.3	1304.9	1268.9
	$L_{21}$ - $M_{11}$ .....	1519.7	1465.5	1417.7 (1418.1)	1325.8	1283.6	1240.1	1199.5
$\beta_{11}\dagger$ $\beta_4$	$L_{11}$ - $M_{11}$ .....		1383.3	1334.4		1204.4	1163.4	
	$L_{11}$ - $M_{21}$ .....	1389.3	1343.1	1298.74 (1298.79)	1215.0	1176.4	1139.8	1104.4
	$L_{22}$ - $N_{11}$ .....	1371.1	1327.4	1287.1 (1287.0)	1204.8	1171.7	1139.8	1110.6
$\beta_1$ $\beta_2$	$L_{21}$ - $M_{22}$ .....	1371.1	1324.23	1279.17 (1279.17)	1194.59	1154.95 (1155.40)	1117.22 (1117.58)	1080.93 (1081.28)
	$L_{11}$ - $M_{22}$ .....	1349.7	1304.1	1260.00 (1259.92)	1177.2	1137.9	1099.50	1065.2
	$L_{22}$ - $N_{22,23}$ .....	1323.5	1281.90	1241.91 (1242.03)	1168.38§	1132.87 (1132.97)	1099.50§ (1099.74)	1067.75§ (1068.01)
$\beta_2''\dagger$ $\beta_2', \beta_2'' \nabla (\beta_2)$			1275.0	1236.0	1161.6	1127.3	1094.1	1061.0
			1274.7	1235.4**		1126.7	1092.8	1060.9
	$L_{22}$ - $O_{11}$ .....	1303.5	1260.9	1220.8	1147.9††	1111.6††	1078.5	1046.5
$\beta_7$ $\beta_7\dagger$	$L_{22}$ - $N_{44,44}$ .....					1108.2	1076.2	1045.3
	$L_{22}$ -limit.....	1293.0	1251.7	1211.6			1070.9	1038.7
	$L_{22}$ - $O_{32,32}$ .....		1251.5	1212.5 (1202.5)	1140	1103.0	1070.1	1038.2
$\beta_2$ $\beta_2\dagger$	$L_{22}$ - $P_{11}$ .....							1036.0
	$L_{11}$ - $M_{22}$ .....		1251.8	1210.5		1097.7	1059.3	1025.4
			1251.5	1209.4			1057.0	1025.7
$\beta_3$ $\beta_3\dagger$	$L_{11}$ - $M_{22}$ .....		1243.0	1203.4	1123.8	1087.4	1052.4	1018.2
			1243.8	1202.1			1051.9	1018.8
	$L_{21}$ - $N_{11}$ .....	1212.1	1170.9	1129.2	1054.1	1019.7	985.5	954.2
$\gamma_1$ $\gamma_{10}\dagger$	$L_{21}$ - $N_{32}$ .....	1176.5	1135.58	1095.53 (1096.30)	1022.47	988.41 (988.76)	955.45 (955.99)	924.37 (924.61)
				1088.7		982.2	950.3	



TABLE 11H.—(Continued)

Lines		72Hf	73Ta	74W*	76Os	77Ir*	78Pt*	79Au*
$\gamma_8$	$L_{21}-O_{11}$ .....			1079				
$\gamma_6$ †	$L_{21}-N_{43}$ .....		1117.6	1078.5	1005.3	971.4	937.9	907.5
$\gamma_6$	$L_{21}-O_{32}$ .....		1110.9	1072.0	999.1	963.6	931.7	901.25
	$L_{21}$ -limit.....	1151.5	1110.2	1071.3			932.1	901.1
$\gamma_2$	$L_{11}-N_{21}$ .....	1141.3	1102.9	1065.84 (1065.88)	995.7	963.6	931.7	901.25
	$L_{21}-P_{11}$ .....							899.0
$\gamma_3$	$L_{11}-N_{22}$ .....	1135.6	1097.1	1059.65 (1059.87)	988.8	956.6	925.6	895.68
$\gamma_9$ †	$L_{11}-N_{33}$ .....			1043.9	975.0	942.6	912.0	883.0
$\gamma_4$	$L_{11}-O_{21,22}$ .....	1100.1	1063.3	1026.47 (1025.8)	957.2	924.5	895.0	866.3
	$L_{11}$ -limit.....	1097	1057	1020.5			892.1	861.3
$\alpha_2$	$K-L_{21}$ .....	226.53	219.73	213.45	201.31	195.50	190.04	184.83
$\alpha_1$	$K-L_{22}$ .....	221.73	214.88	208.62	196.45	190.65	185.23	179.96
$\beta_4$	$K-M_{21}$ .....	195.83						
$\beta_1$	$K-M_{22}$ .....	195.15	189.91	184.22	173.61	168.50	163.70	159.02
$\beta_2$	$K-N_{21,22}$ .....	190.42	184.52	178.98	168.75	163.76	158.87	154.26
	$K$ -limit.....	190.1	183.6	178.07			158.1	153.4

\* Friman's measurements (81) of the stronger lines are given in ( ) and are more accurate than the older values; he did not measure the fainter lines.

† Satellites of diagram lines: not resolved in any photograph (83).  $M\alpha$  and  $M\beta$  are unresolved multiplets, for details of structure, see (166).

‡ Non-diagram lines listed by Dauvillier (5, 47); if a difference notation is given, it is to be regarded as tentative. In this table, Dauvillier's  $\beta_7$  and  $\beta'_7$  are entered as  $\beta'_7$  and  $\beta_7$ , respectively. His  $\beta'_7$ ,  $\beta_8$ ,  $\beta_9$  are, respectively, same as Siegbahn's  $\beta_8$ ,  $\beta_9$ ,  $\beta_{10}$ .

§ Dauvillier (5, 47, 48) lists separately  $\beta'_7$  with  $\lambda_{Os} = 1170.2$ ,  $\lambda_{Pt} = 1100.9$ ,  $\lambda_{Au} = 1069.75$ .

|| Dauvillier (5, 47) lists  $\beta'_7\lambda = 1062.3$  for 79Au.

¶ Non-diagram lines listed by Siegbahn (142).

\*\* Same observer lists this value for  $\beta_{11,12}$  also.

†† As measured by Dauvillier and called by him  $\beta'_7$ ; his  $\beta_7$  is the neighboring non-diagram line  $L_{21}-N_{43,44}$ .

I. Sources (except as otherwise noted).—Absorption limit:  $K$ -limits (59);  $L$ -limits, 88Ra (19), others (63, 66);  $M$ -limits (34, 154). Emission:  $K$ -series, 92U (135), others (58);  $L$ -series in ( ) (81), 80Hg (75), 84Po and 88Ra (19), 92U ( $\gamma_4$  and  $L_{11}-P_{21,22}$ ) (47), others (142);  $M$ - and  $N$ -series (83).

Lines		80Hg*	81Tl†	82Pb‡	83Bi†	84Po	88Ra	90Th†	92U†
	$N_{27}-O_{32,33}$ .....							13 805	12 874
	$N_{27}-P_{11}$ .....							13 149	12 250
	$N_{21}-O_{32}$ .....							11 046	10 385
	$N_{11}-O_{21,22}$ .....							10 030	9 619
	$N_{11}-P_{21,22}$ .....							9 397	8 691
	$M_{37}-N_{22}$ .....			6 727	6 498			5 245	4 929
$\alpha_2$	$M_{27}-N_{11}$ .....		5 879	5 687	5 525			4 569	4 326
$\alpha_1$	$M_{37}-N_{43}$ .....				5 117			4 138	3 913
$\alpha'\S$	$M_{37}-N_{44}$ .....		5 443	5 273	5 107			4 129	3 901
$\alpha'\S$			5 427	5 250	5 078			4 097	3 885
$\beta$	$M_{37}-N_{45}$ .....		5 233	5 065	4 894			3 931	3 709
$\beta'\S$			5 210	5 042	4 875			3 925	3 696
$\beta'\S$								3 921	3 684
	$M_{37}-O_{21,22}$ .....		5 185	4 994	4 815			3 792	3 570
	$M_{37}-P_{22}$ .....							3 753	3 514
	$M_{37}$ -limit.....				4 762			3 721	3 491
$\gamma$	$M_{27}-N_{32,33}$ .....		4 806	4 666	4 513			3 657	3 472
$\gamma'\S$			4 798		4 497			3 645	3 459
	$M_{37}$ -limit.....				4 569			3 552	3 326
	$M_{21}-N_{11}$ .....			4 646	$x$			3 530	3 321
	$M_{27}-O_{11}$ .....							3 276	3 107
	$M_{27}-O_{22,23}$ .....							3 109	2 927
	$M_{11}-N_{21}$ .....				3 884			3 127	2 909
	$M_{27}$ -limit.....				3 894			3 058	2 873
	$M_{21}-N_{32}$ .....		4 095	3 945	3 816			2 999	2 815
	$M_{11}-N_{22}$ .....		3 932	3 789	3 672			2 917	2 750
	$M_{21}-O_{32}$ .....							2 612	2 439
	$M_{21}$ -limit.....							2 571	2 385
	$M_{11}-O_{21,22}$ .....							2 437	2 299
	$M_{11}-P_{21,22}$ .....								2 248



TABLE 11I.—(Continued)

Lines		80Hg*	81Tl†	82Pb‡	83Bi†	84Po	88Ra	90Th†	92U†
l	M <sub>11</sub> -limit.....							2 388	2 228
	L <sub>22</sub> -M <sub>11</sub> .....	1 418.41		1 346.62	1 312.95			1 112.41	1 064.77
s¶		1 380.6**							961.7
α <sub>2</sub>	L <sub>22</sub> -M <sub>32</sub> .....	1 249.51	1 216.03	1 183.52	1 153.3			965.24	920.14
α <sub>1</sub>	L <sub>22</sub> -M <sub>33</sub> .....	1 238.48	1 204.71	1 172.02	1 141.15	1 101	1 010	953.42	908.33
			(1 204.93)	(1 172.58)	(1 141.50)			(954.05)	(908.74)
η	L <sub>21</sub> -M <sub>11</sub> .....	1 161.6	1 125	1 090.2	1 057				802.9
β <sub>6</sub>	L <sub>22</sub> -N <sub>11</sub> .....	1 076.8	1 048.0	1 018.8	991.6			826.2	786.6
β <sub>4</sub>	L <sub>11</sub> -M <sub>31</sub> .....	1 069.2	1 037.1	1 004.69	975.4			789	745.4
β <sub>1</sub>	L <sub>21</sub> -M <sub>32</sub> .....	1 045.49	1 012.66	979.90	949.30	920		762.59	718.07
			(1 012.99)	(980.83)	(950.02)			(763.56)	(718.51)
β <sub>2</sub>	L <sub>22</sub> -N <sub>22,23</sub> .....	1 036.55	1 007.86	979.90	952.93			791.08	752.68††
			(1 008.22)		(953.24)			(791.92)	(753.07)
β <sub>3</sub> ††		1 030.46		973.5					
β <sub>2</sub>	L <sub>11</sub> -M <sub>21</sub> .....	1 030.46	997.8	966.02	935.7			752.1	708.4
β <sub>2</sub> ¶¶									745.9
β <sub>7</sub> ¶	L <sub>22</sub> -N <sub>43,44</sub> .....								734.0
β <sub>7</sub>	L <sub>22</sub> -O <sub>11</sub> .....	1 015.5	988	959.0					736
β <sub>5</sub>	L <sub>22</sub> -O <sub>32,33</sub> .....	1 006.7	978.3	949.52	922.3			762.59	724.13
	L <sub>22</sub> -limit.....		977.9	950.0	921.9		802	759.9	721.6
β <sub>5</sub> ¶	L <sub>11</sub> -M <sub>32</sub> .....	984.2							685.3
β <sub>5</sub> ¶	L <sub>11</sub> -M <sub>33</sub> .....								679.7
β <sub>5</sub> ††				922.3	893.8				
γ <sub>5</sub>	L <sub>21</sub> -N <sub>11</sub> .....	922.9	894.2	863.9	837.8				
γ <sub>1</sub>	L <sub>21</sub> -N <sub>32</sub> .....	893.53	865.29	837.08	810.65			651.03	612.83
			(865.71)	(838.01)	(811.43)			(651.76)	(613.59)
γ <sub>2</sub>	L <sub>11</sub> -N <sub>21</sub> .....	872.4	844.7	818.2	792.9				604.4
γ <sub>3</sub>	L <sub>11</sub> -N <sub>22</sub> .....	866.2	837.9	813.70	787.4				597.0
γ <sub>6</sub>	L <sub>21</sub> -O <sub>32</sub> .....	872.4	841.7	813.70	787.4			630.1	592.6
	L <sub>21</sub> -limit.....	870.3	841.8	813.6	787.4		668	628.8	592.0
γ <sub>4</sub>	L <sub>11</sub> -O <sub>21,22</sub> .....	836.1	810.0	783.6	761				573.8
	L <sub>11</sub> -P <sub>21,22</sub> .....								568.9
	L <sub>11</sub> -limit.....	833.8	805.8	780.6	756.5			604.6	568.7
α <sub>2</sub>	K-L <sub>21</sub> .....		174.66	170.04	165.25				130.95
α <sub>1</sub>	K-L <sub>22</sub> .....		169.80	165.16	160.41				126.40
β <sub>2</sub>	K-M <sub>31</sub> .....		150.11	146.06	142.05				111.87
β <sub>1</sub>	K-M <sub>22</sub> .....								
β <sub>2</sub>	K-N <sub>21,22</sub> .....		145.39	141.25					108.42
	K-limit.....	149.1	144.8	141.0	137.2			113.1	107.5

\* For 80Hg there are also β<sub>15</sub> = 993.6 and the unallocated lines 907.6, 882.9, and 856.4, all from (75). See also note "†."

† Friman's measurements (81) of the stronger lines are given in ( ) and are more accurate than the older values; he did not measure the fainter lines.

‡ The λ's of the L-series of Hönigschmidt's Ra-G (atomic weight = 206.05) are identical (within 0.5mÅ) with those of ordinary Pb (atomic weight = 207.18) (148); those of the L<sub>α1</sub> line of such leads are identical within 0.006mÅ (29); those of the absorption limits of two of Richards' leads (atomic weight = 206.08 and 207.20) are identical within 1mÅ (79). See also note "†."

§ Satellites of diagram lines; not resolved in any photograph (82).

|| In spectrum of 92U, Mβ' and Mγ' are each accompanied by a satellite: β''λ = 3700, γ'λ = 3466.

¶ Non-diagram lines listed by Dauvillier (5, 47); if a difference notation is given, it is to be regarded as tentative. In this table, Dauvillier's β<sub>7</sub> and β<sub>1</sub> are entered as β<sub>7</sub>' and β<sub>1</sub>', respectively. His β<sub>2</sub>', β<sub>3</sub>', β<sub>4</sub>' are, respectively, the same as Siegbahn's β<sub>2</sub>, β<sub>3</sub>, β<sub>4</sub>.

\*\* An unallocated line; not s.

†† Dauvillier (5, 47, 48) lists separately β<sub>2</sub>'λ = 754.68 for 92U.

‡‡ Non-diagram lines listed by Siegbahn (142).

## Notes regarding the data of Table 11

Lit.	Remarks	Lit.	Remarks
(19)	Error not stated.	(47)	Values for strong lines are generally within 0.1mÅ of Siegbahn's, but for such lines as Lβ <sub>2</sub> and Lβ <sub>4</sub> they depart irregularly by about 0.4mÅ.
(23)	Neither error nor value used for grating-space is given.	(5, 48)	Probable error estimated as some tenths of mÅ. Values are based upon Siegbahn's values for K-lines of 26Fe and 29Cu.
(24)	Used rock salt and Siegbahn's value d <sub>r</sub> = 2.814 Å, but values may not be strictly comparable with those obtained with calcite.	(59)	Probable error estimated as < 1%; recomputation would add only 0.5 unit in last figure.
(32)	Probable error Kβ <sub>2</sub> may amount to 0.24mÅ; of others it is 0.08mÅ.	(60)	Probable error not stated; used ionization spectrometer and estimated position of middle point of the discontinuity to within 0.1% of glancing angle.
(33)	These revised data agree fairly well with those by (109).		
(34)	Error not stated.		
(37)	Error estimated as 2mÅ.		



Notes regarding the data of Table 11.—(Continued)

Lit.	Remarks
(63, 66)	Error estimated as 0.3 or 0.4 mÅ for most of $L_{21}$ - and $L_{22}$ -limits, and, on the average, as ca. 0.9 mÅ for $L_{11}$ -limits. Data have been recomputed on basis of $d_e = 3.02904 \text{ Å}$ (see Table 9).
(75)	Measurements for 80Hg were relative to neighboring lines of other elements; $\lambda$ 's used for latter were not very accurate.
(72, 80)	Error not stated; crystal was sugar; data have not been recomputed, those for 12Mg and 13Al are the least accurate.
(83)	Error estimated as 2' to 4' in the doubled glancing angle; i.e., 1.5 to 3 mÅ for calcite and more for gypsum and sugar; all three crystals were used. In certain cases, his difference notation has been changed to conform with indications of the selection rules (p. 31). Dolejšek (55) questions the correctness of some of the transitions assigned to lines of the N-series, but the alternatives he proposes seem to be inconsistent with the observed intensities.
(105)	Measurements carefully made and usually agree with those of (108) within 0.1 or 0.2 mÅ.
(108)	Probable error not > few units in last figure; work was done in Siegbahn's laboratory.
(110)	Values based on $\lambda = 1242.1 \text{ mÅ}$ for $L\beta_2$ of W and on white lines, at 2515.7 mÅ and 2451.5 mÅ, due to Overn effect (131) in his rock salt crystal; assumes $d_r = 2.8125 \text{ Å}$ . Data not recomputed as the assumed value of $L\beta_2$ of W is essentially that given in Table 9.
(114)	Error not stated; individual plates differ from the mean by only 0.1 or 0.2 mÅ.
(116, 117)	A careful investigation.
(118)	Error not stated. Part of the work was done with Siegbahn's precision spectrometer.
(135)	Probable error = 0.1 mÅ. Used de Broglie's rotating crystal method. Kind of crystal is not stated, but probably differences between his values and Cork's (32) may be judged from their values for W as given in Table 9.
(142)	Probable error in K-series is not > a few units in last figure.
(151)	Most of their values are given only to nearest 10 mÅ. They do not state to which $L\beta$ their measurements apply, presumably it is $L\beta_1$ .
(154)	Error not stated.
(167)	Probable error of $K\alpha_1$ and $K\alpha_2 = 0.04 \text{ mÅ}$ , of $K\beta_1 = 0.06 \text{ mÅ}$ .

## ABSORPTION LIMITS

As the wave-length ( $\lambda$ ) of the radiation is varied the coefficient of absorption of a given substance changes abruptly as  $\lambda$  passes through certain definite values. These values are known as the absorption limits of the substance, and have been found to coincide with the limiting frequencies of the emission series characteristic of the absorber; for more detailed information, see Absorption and

scattering of X-rays, p. 8. In this section we are concerned only with the fine structure of these limits and with the effect of chemical combination. For numerical values of the limits, see Tables 10 and 11.

TABLE 12.—ABSORPTION LIMITS: FINE STRUCTURE AND EFFECT OF CHEMICAL COMBINATION

The limits for certain elements have a fine structure (38, 72, 80). The structure on the long- $\lambda$  side may be due to a partial reduction of the compound (113, 114); that on the short- $\lambda$  side is observed only when the absorbing screen is thin. In addition to the following data, very extensive and detailed investigations may be found in (4, 153).

Roman subscripts indicate the valency of the element in the compound studied.  $\Delta V_e$  = amount by which the equivalent excitation potential for the compound exceeds that for the uncombined element;  $\Delta V_e = \left(\frac{1}{\lambda_e} - \frac{1}{\lambda_c}\right) \frac{hc}{e} = hc\Delta\lambda / e\lambda_c\lambda_e$ , where  $\lambda_c[\lambda_e]$  = wave-length of absorption limit for compound [for element] and  $\Delta\lambda = \lambda_e - \lambda_c$ . On basis of I. C. T. accepted constants (Vol. I, p. 17),  $hc/e = 12344 \text{ volt Å}$ .  $K_1$  = principal K-limit,  $K_2$  = secondary absorption edge; in each case  $\lambda$  corresponds to the low frequency edge of the line;  $\delta\lambda$  = width of line (cf. Fig. 14); av. = average. Unit of  $\lambda = 1 \text{ mÅ} = 0.001 \text{ Å} = 10^{-11} \text{ cm}$ ; of  $\Delta V = 1 \text{ volt}$ .

Z	Absorber	$\lambda$	$\Delta V_e$	Lit.
K-limit				
14	Si*	6731.0		(114)
	Sirv	6707.5	6.4	(114)
15	P(white)*	5776.9		(152)
	P(black)	5771.5	2.0	(152)
	Hypophosphites	5757.5	7.2	(152)
	Phosphites	5754.1	8.4	(152)
	Phosphates	5750.7	9.7	(152)
16	S (see below)			
17	Cl (see below)			
19	K*	3431.0		(113)
	KCN	3429.3	1.8	(113)
	KCNS	3428.7	2.4	(113)
	KI	3428.3	2.8	(113)
	KCl	3428.0	3.1	(113)
	$K_2S_2O_8$	3427.3	3.9	(113)
	$K_2SO_4$	3426.7	4.5	(113)
	$KClO_4$	3426.3	4.9	(113)
20	Ca (see below)			
21	Sc			
	$Sc_2(SO_4)_3$	2751.7		(72, 80)
22	Ti*	2491.2		(114)
	$TiO_2$	2482.6	17.0	(114)
23	V*	2263.0		(114)
	$V_v(\text{av.})$	2257.1	14.2	(114)
24	Cr*	2066.3		(114)
	$Cr_2S_3$	2063.9	6.9	(114)
	$Cr(OH)_3$	2061.9	12.7	(114)
	$Cr_2(SO_4)_3$	2062.2	11.9	(114)
	$Cr_v(\text{av.})$	2059.7	19.1	(114)
25	Mn*	1892.1		(114)
	$Mn_{II}(\text{av.})$	1889.3	9.7	(114)
	$MnO_2$	1887.7	15.2	(114)
	$KMnO_4$	1886.3	20.0	(114)
26	Fe*	1740.5		(114)
	FeS	1738.9	6.5	(114)
	$FeSO_4$	1738.3	9.0	(114)
	$Fe_{II}(\text{av.})$	1737.2	13.5	(114)



TABLE 12.—(Continued)

Z	Absorber	$\lambda$ (142)		$\delta\lambda$		$\Delta V_e$		$\Delta V$
		$K_1$	$K_2$	$K_1$	$K_2$	$K_1$	$K_2$	$K_2-K_1$
17	Cl <sub>2</sub> *	4393.8	4381.6	7.5				7.8
	HCl	4385.3				5.4		
	Chlorides	4382.9	4360.0	11.3		7.0	13.8	14.6
	Chlorates	4376.9	4357.4	9.6		10.8	15.5	12.5
	Perchlorates	4369.8	4347.8	9.7	15.9	15.3	21.6	14.1
	(See Fig. 14)							
16†	S mon.†	5009.0	4994.6	8.5	8			
	S rhom.†	5008.6	4993.8	7.7	7.7			
	S* cryst.†	5008.8	4994.1	8.1	7.9			
	Sulfides§	5009.3						
	Sulfites	4996.0	4988.1	4.3	4.2	6.3		
	SO <sub>2</sub>	5004.5	4996.4	4.0		2.1		
	Sulfates	4987.9		5.2		10.3		
	SII¶	5006.8						
	SIV¶	5001.9		5.5		3.4		
	SVI¶	4993.9		5.7		7.3		

Z	Absorber	$\lambda$ (119)				$\Delta V$		
		$K_1$	$K_2$	$K_3$	$K_4$	$K_2-K_1$	$K_3-K_1$	$K_4-K_1$
20Ca	Ca*(av.)	3064.3	CaCO <sub>3</sub> (av.); 3060.5	$\Delta V_e = 5.0$ (78)				
	CaCO <sub>3</sub>	3060.8	3050.2	3037.9	3023.8	13.8	29.5	49.1
	CaSO <sub>4</sub> ·2H <sub>2</sub> O	3059.1	3047.5	3035.8		15.3	31.6	
	CaF <sub>2</sub>	3059.9	3047.8	3034.6	3025.8	16.0	33.7	46.2

Z	Absorber	L-limits				
		$L_{22}$	$(\Delta V_e)_{22}$	$\Delta\lambda_l^{**}$	$\Delta\lambda_d^{**}$	Lit.
50	Sn*	3146.9				(25)
	SnO <sub>2</sub>	3140.6	8	6.9	5.6	(25)
51	Sb*	2991.5				(25)
	Sb <sub>2</sub> O <sub>3</sub>	2985.1	9	6.0		(25)
	KSbO <sub>3</sub>	2984.1	10	6.7	7.1	(25)
	Sb*	2993.0				(93)
	Sb <sub>2</sub> O <sub>3</sub>	2987.4	7.7			(93)
	Sb <sub>2</sub> S <sub>3</sub>	2987.9	7.0			(93)
	SbI <sub>3</sub>	2988.7	5.9			(93)
	SbOCl	2989.4	5.0			(93)
	KSbOC <sub>2</sub> O <sub>4</sub> ††	2987.9	7.0			(93)
	KSbOC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> ††	2988.5	6.2			(93)
	Sb <sub>2</sub> O <sub>3</sub> ·nH <sub>2</sub> O	2986.7	8.7			(93)
	Sb <sub>2</sub> S <sub>6</sub>	2991.0	2.8			(93)
	Cu(SbO <sub>3</sub> ) <sub>2</sub> ·nH <sub>2</sub> O	2987.4	7.7			(93)
	K <sub>2</sub> H <sub>2</sub> Sb <sub>2</sub> O <sub>7</sub>	2986.2	9.4			(93)
52	Te*	2847.1				(38)
	H <sub>2</sub> TeO <sub>3</sub>	2842.2	7	4.7		(38)
	H <sub>2</sub> TeO <sub>4</sub>	2840.6	10	6.0	5.6	(38)
53	I*	2712				(38)
	KI	2712.2	0.3			(38)
	HIO <sub>3</sub>	2707.1	9	4.4	6.1	(38)
	HIO <sub>4</sub>	2705.8	11	5.5		(38)

\* Absorber from which  $\Delta V_e$  is measured.

† In general, SII has a pure edge type of limit, while SIV and SVI exhibit absorption lines; the observed subordinate limit of SIV may really be principal limit of SVI, as result of oxidation of the SIV (111, 112).

‡ Mon. = monoclinic; rhom. = rhombic; cryst. = crystallized. Data are averages.

§ Position of both  $K_1$  and  $K_2$ , especially  $K_2$ , depends upon the nature of the metal ion.|| For  $K_1$ ,  $\lambda$  is independent of nature of metal ion; for  $K_2$  it increases as Z of metal ion increases.

¶ Organic compounds.

\*\*  $\lambda(L_{22}) + \Delta\lambda_l = \lambda$  of a light line which probably (25) is the  $L_{22}$ -limit of the element formed by a reduction of the compound.  $\lambda(L_{22}) - \Delta\lambda_d = \lambda$  of maximum of a broad, diffuse, dark line which appears only when absorbing screen is thin.

†† Potassium antimonyl oxalate.

‡‡ Potassium antimonyl tartrate.

TABLE 12.—(Continued)

Z	Absorber	$L_{11}$	$(\Delta V_e)_{11}$	$L_{21}$	$(\Delta V_e)_{21}$	$L_{22}$	$(\Delta V_e)_{22}$	$L_{31}$
53	I*	2402		2548		2711		(159)
	NaI	2397	11	2542	12	2708	5	(159)
	NaIO <sub>3</sub>	2398	9	2544	9	2709	4	(159)
	NaIO <sub>4</sub>	2397	11	2541	14	2703	13	(159)

M-limits§§

Z	$M_{22}$		$M_{32}$		$M_{33}$			
	g	e	g	e	g	e	g	e'
90Th	3058.5	3046.3	3552.3	3538.9	3721.3	3704.5		
92U	2873.4	2865.2	3325.5	3312.4	3490.7	3473.7	3458.7	3449.2

§§ Passing from longer to shorter  $\lambda$ 's, the intensity of the transmitted radiation varies as follows: At g there is an abrupt decrease in intensity, that is the limit itself; at e there is an increase in intensity; at g' there is a second decrease, followed by another increase at e'.

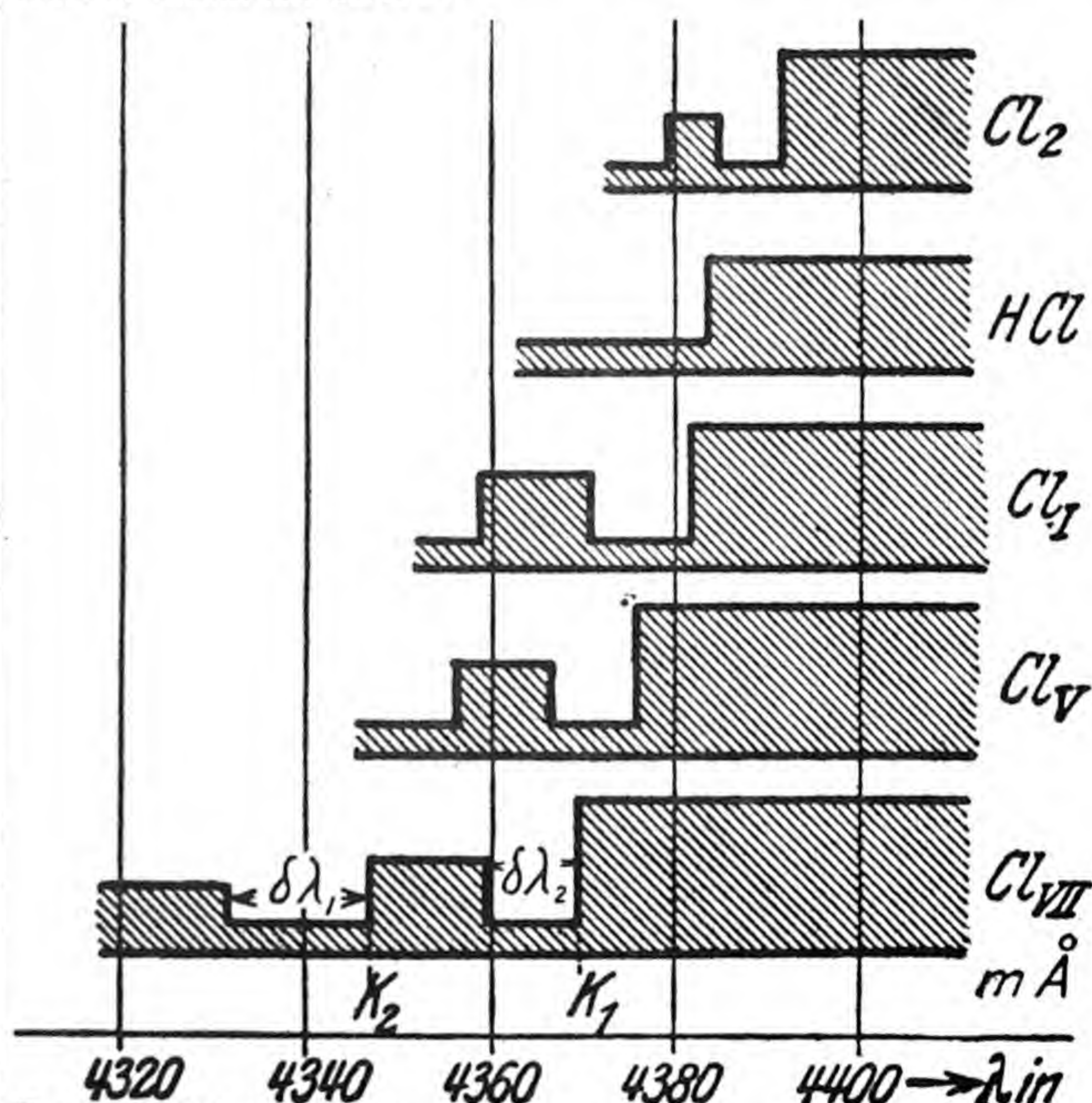


FIG. 14.—Relative positions and structure of the K absorption limit of Cl in certain compounds: Diagrammatic. (After Siegbahn (142).)

$K_1$  is the principal limit,  $K_2$  is a secondary edge. The subscripts I, V, VII indicate that the Cl was contained in chlorides, chlorates, and perchlorates, respectively.

## CONTINUOUS SPECTRA

All data discussed in this section were obtained with unvarying voltages; the power transmitted by the radiation is proportional to the cathode-ray current (14), and is plotted as ordinates in the figures. (With gas-filled tubes an appreciable fraction of the tube-current may be due to positive ions.) With a fluctuating voltage, the spectral distribution of the energy is much like that with an unvarying V equal to the peak voltage, but there is more energy in the longer waves (43); the intensity is practically that due to such current as flows during the part of the cycle when V is near its peak value.

Practical workers are interested in the spectral distribution of the energy in the radiation that emerges from the tube. This is roughly indicated in Figs. 15 and 16.

For exact information about atoms and the mechanism of radiation, observed data must be so corrected as to give an actual measure of the X-ray energy emitted by the atoms of the target; and, for the purposes of this section, the last is further corrected so as to eliminate the energy contributed by the characteristic line



spectrum of the target. The distribution of energy in such a corrected continuous spectrum is shown in Figs. 17 and 18.

The spectral, or monochromatic, intensity ( $J_{\psi\nu}$ ,  $J_{\psi\lambda}$ ) of the radiation in the direction  $\psi$  (v. Fig. 19) is defined by the equations  $J_{\psi} = \int_0^{\nu_0} J_{\psi\nu} d\nu = \int_{\lambda_0}^{\infty} J_{\psi\lambda} d\lambda$ , where  $\nu_0$  and  $\lambda_0$  correspond to the high-frequency limit of the spectrum,  $\nu_0$  being defined by the equation  $Ve = h\nu_0$  in which  $V$  is the voltage on the tube;  $cJ_{\psi\nu} = \lambda^2 J_{\psi\lambda}$ . The excitation voltage ( $V_0$ ) for radiation of frequency  $\nu$  is  $V_0 = h\nu/e$ . For notation and general remarks concerning the origin of X-rays and the high-frequency limit of the continuous spectrum, see p. 24 and 27.

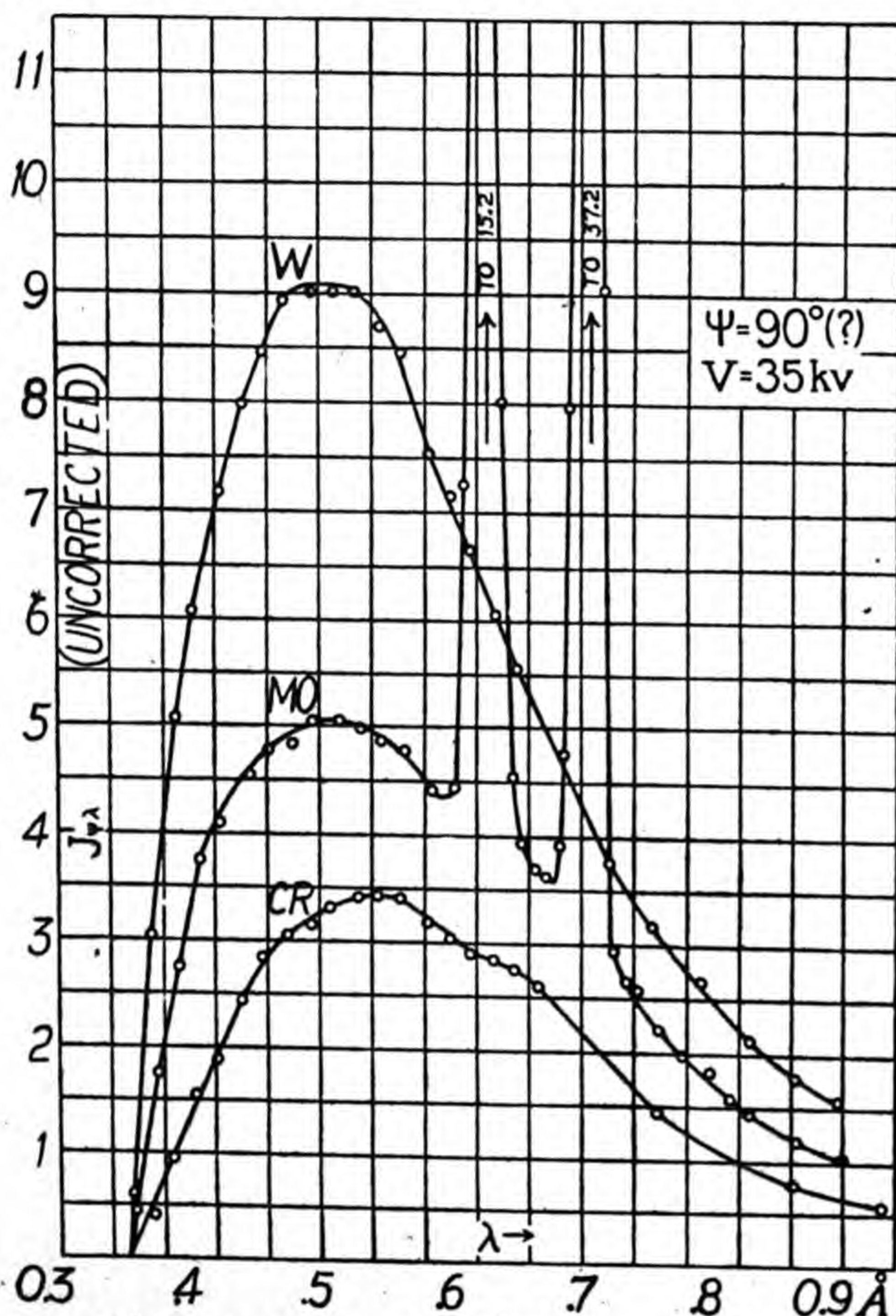


FIG. 15.—Variation of observed (uncorrected) spectrum with material of target (128).

Tube potential and current were unvarying and the same for all.

Under all conditions yet investigated, for radiation from the focal spot,  $J_{\psi\nu} d\psi d\nu = CZ[(\nu_0 - \nu) + x] \sin \psi d\psi d\nu$ ,  $C$  is a constant, and  $x$ , which is comparatively unimportant, is in general a function of  $Z$ ,  $\psi$ ,  $\nu$ , and  $\nu_0$ . The  $(\nu_0 - \nu)$  term is well established, but investigators disagree regarding the  $x$ -term. At low voltages (7 to 12 kv) and  $\psi = 90^\circ$ ,  $x = bZ(1 - e^{-(\nu_0 - \nu)/\nu_1})$  for a wide range of  $Z$  (172, 176) if  $b = 0.0025 \times 10^{18} \text{ sec}^{-1}$  and  $\nu_1 = 0.07 \times 10^{18} \text{ sec}^{-1}$  (cf. Figs. 20 and 21). At higher voltages (10 to 80 kv), the isochromat method (Figs. 22 and 23) has usually been used,  $Z$  has been varied from 29 to 78, and  $\psi$  has been near  $90^\circ$  (177, 186); but in the most recent work (126),  $\psi$  has been varied. In that (126),  $V$  was varied from 15 to 80 kv, and it was found that, for  $Z = 29$ ,  $x = b'Z\nu_0(1 - e^{-u(\nu_0 - \nu)/\nu_1})$ , where for  $\psi = 90^\circ$ ,  $b' = 0.0027 \pm 0.0005$ ; for  $\psi = 36^\circ$ ,  $b' = 0.0033 \pm 0.0004$ ; and for  $\psi = 144^\circ$ ,  $b'$

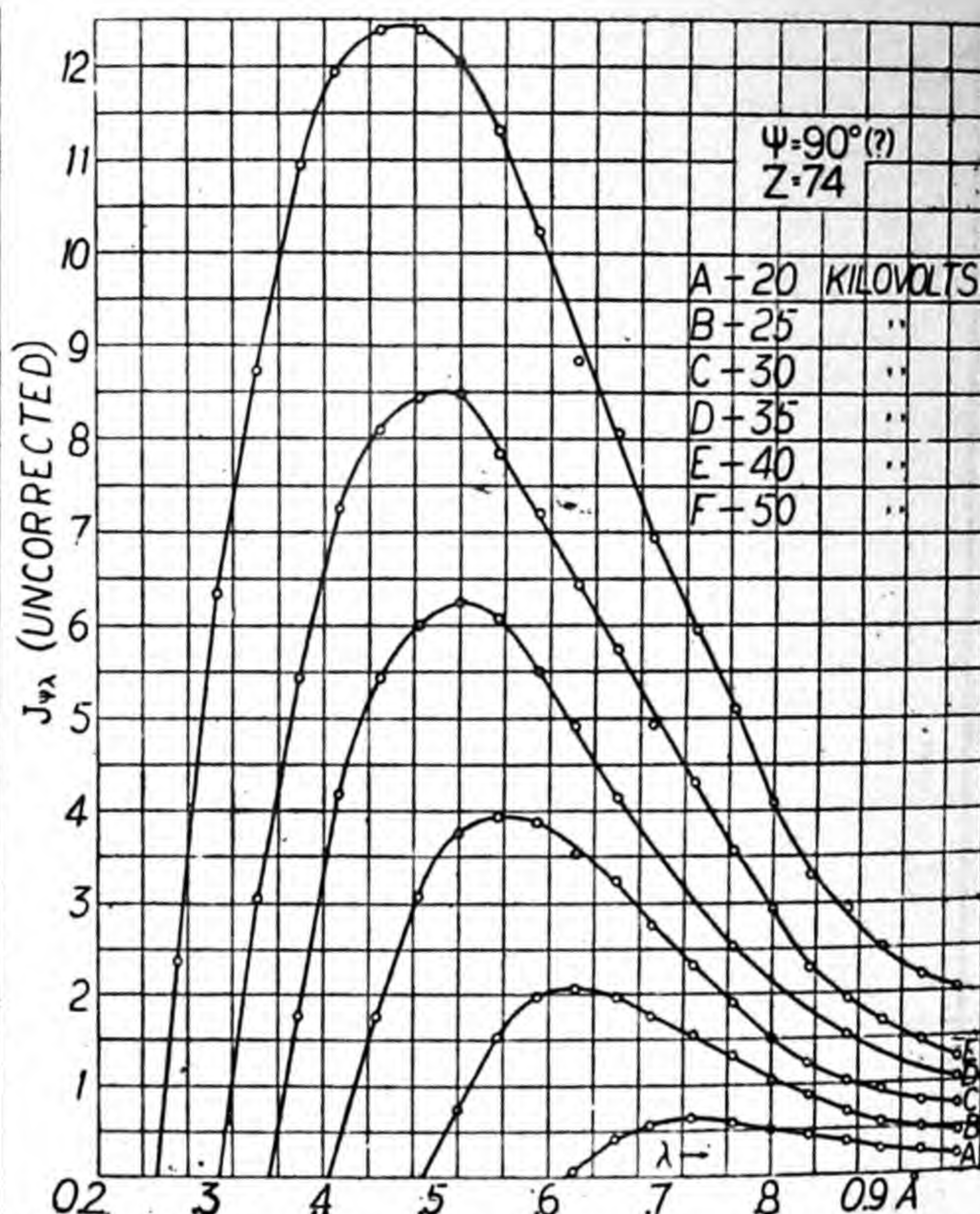


FIG. 16.—Variation of observed (uncorrected) spectrum with tube potential and current constant (128).

In each case the tube potential was unvarying. The tube current was the same in all cases. A standard Coolidge tube with tungsten (W) target was used.

is, in general, negative, progressing from ca. 0 for  $V_0 = 15 \text{ kv}$  to ca.  $-0.0015$  for  $V_0 = 50 \text{ kv}$ . The original interpretation of these data was in error; a revision is soon to be published. The total X-ray energy emitted by the focal spot is

$$\int_0^{180^\circ} J_{\psi} d\psi = \int_0^{180^\circ} \sin \psi d\psi \int_0^{\nu_0} CZ[(\nu_0 - \nu) + x] d\nu = KZV^2 + CZ \int_0^{180^\circ} \sin \psi d\psi \int_0^{\nu_0} x d\nu = \text{ca. } KZV^2$$

as  $x$  is small, positive for some values of  $\psi$  and negative for others;  $K$  depends upon  $C$ , but is independent of  $Z$  and of  $V$ .

The radiation from the focal spot, to which the formula applies, does not represent all the X-ray energy generated, as a very appreciable fraction of the cathode ray is so deflected from the focal spot as to strike other portions of the target with sufficient velocity to produce X-rays. Probably this effect is much influenced by the smoothness of the target face, and by its inclination to the cathode stream; this may account for the disagreement regarding the  $x$ -term. The amount of this stray energy is of the order of 20% of the whole (30, 31), and its spectral distribution is of the same mathematical form as that of the energy from the focal spot,  $x$  having a relatively large negative value (126). For given conditions, the variation of  $x$  with  $\psi$  is only slightly affected by the presence of this stray radiation (126).

Using the best value of  $C$  (102) in calculating the total energy in the continuous spectrum, the efficiency (X-ray energy per volt-ampere of cathode ray current) is found to be  $E = (9.5 \pm 3) \times 10^{-10} ZV$ , where  $V$  is expressed in volts. It is claimed (102) that, in the method of measurement of cathode ray current through the gas-filled tubes used for the above evaluation of  $C$ , the stray radiation is automatically corrected for. The best experimental



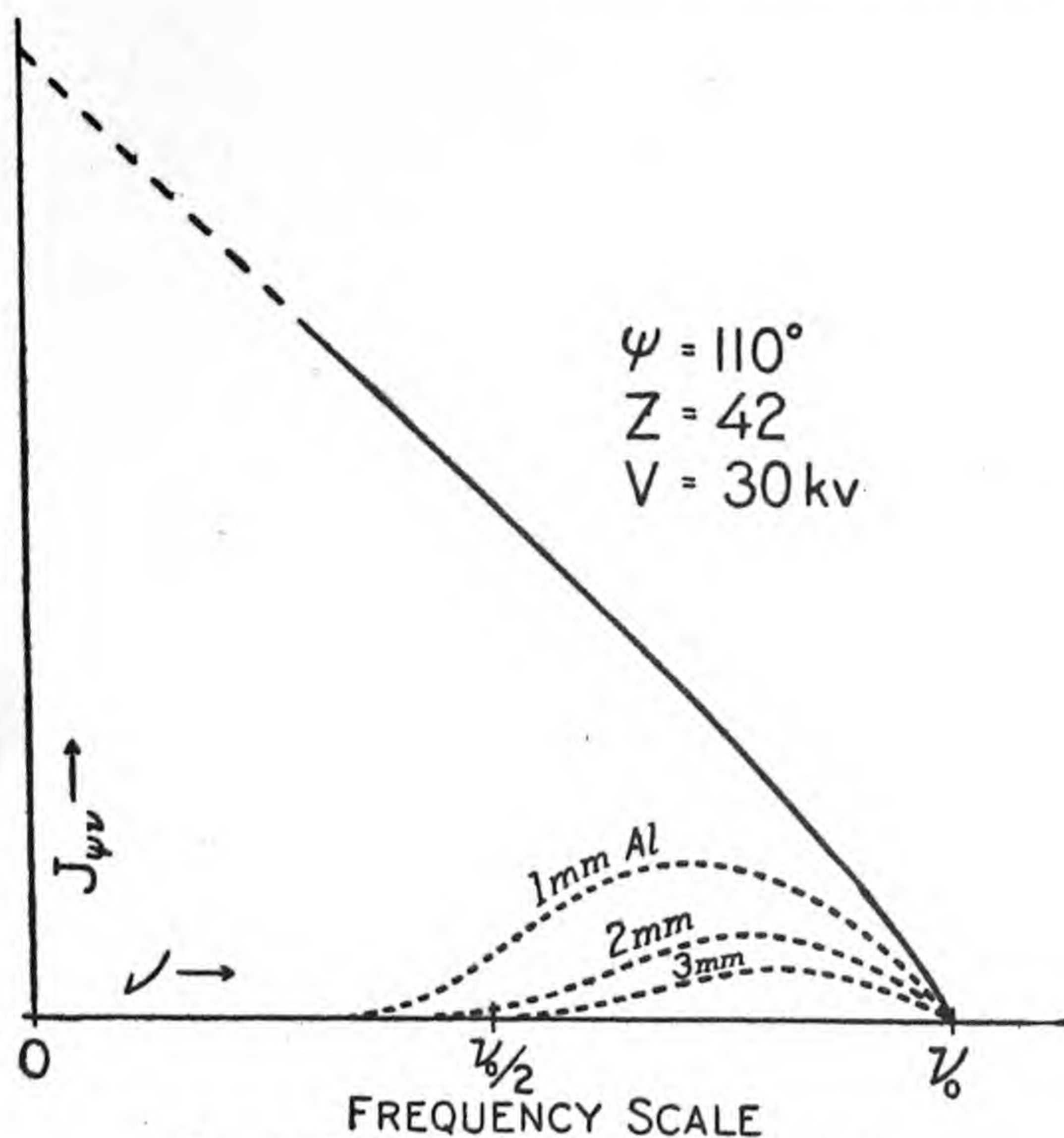


FIG. 17.—Fully corrected frequency spectrum (181).

Full line represents the spectrum as emitted by the atoms of the target; the lower broken lines represent the same after filtration by Al, or, qualitatively, by any filter without absorption limits in the region considered.

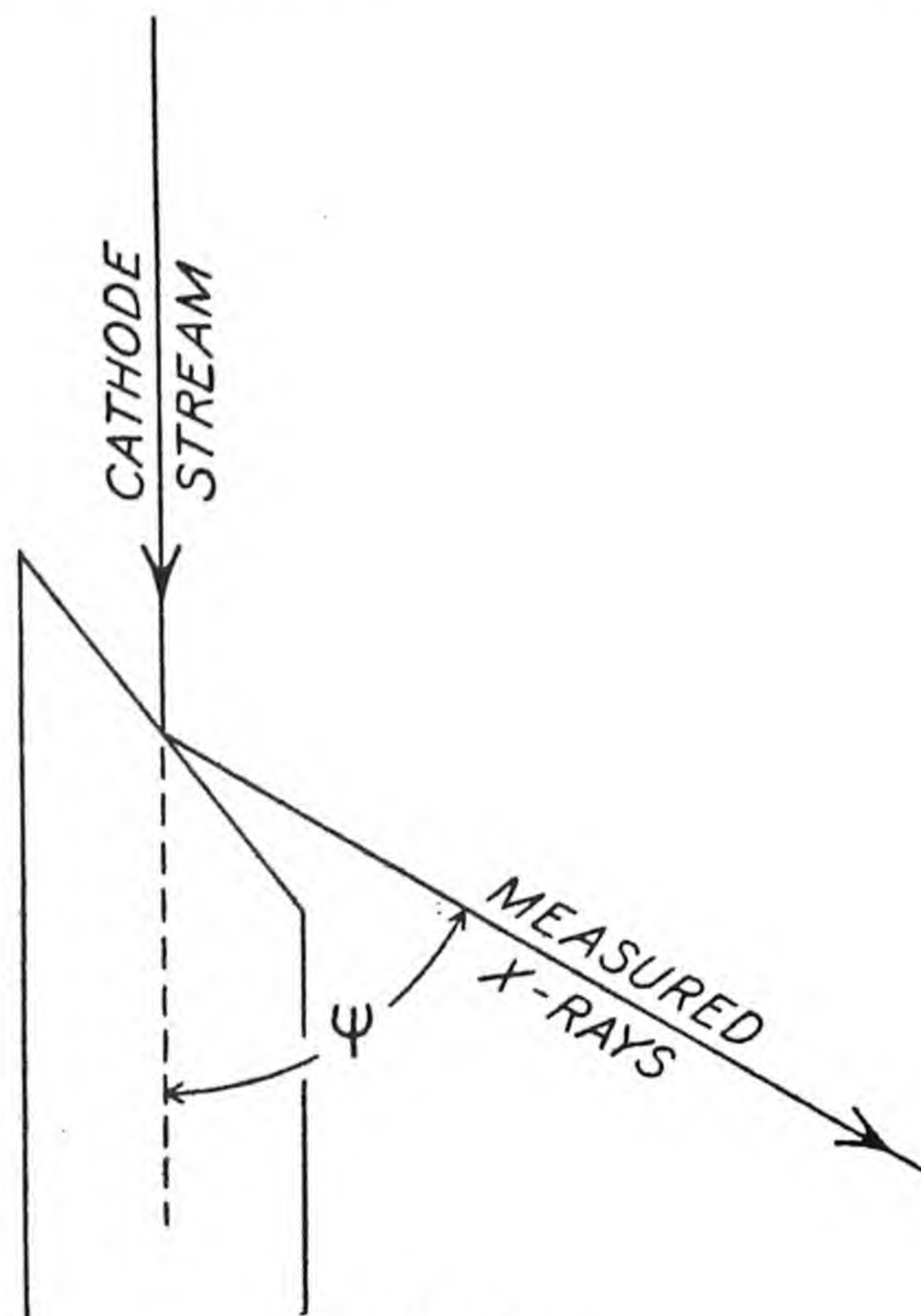


FIG. 19.

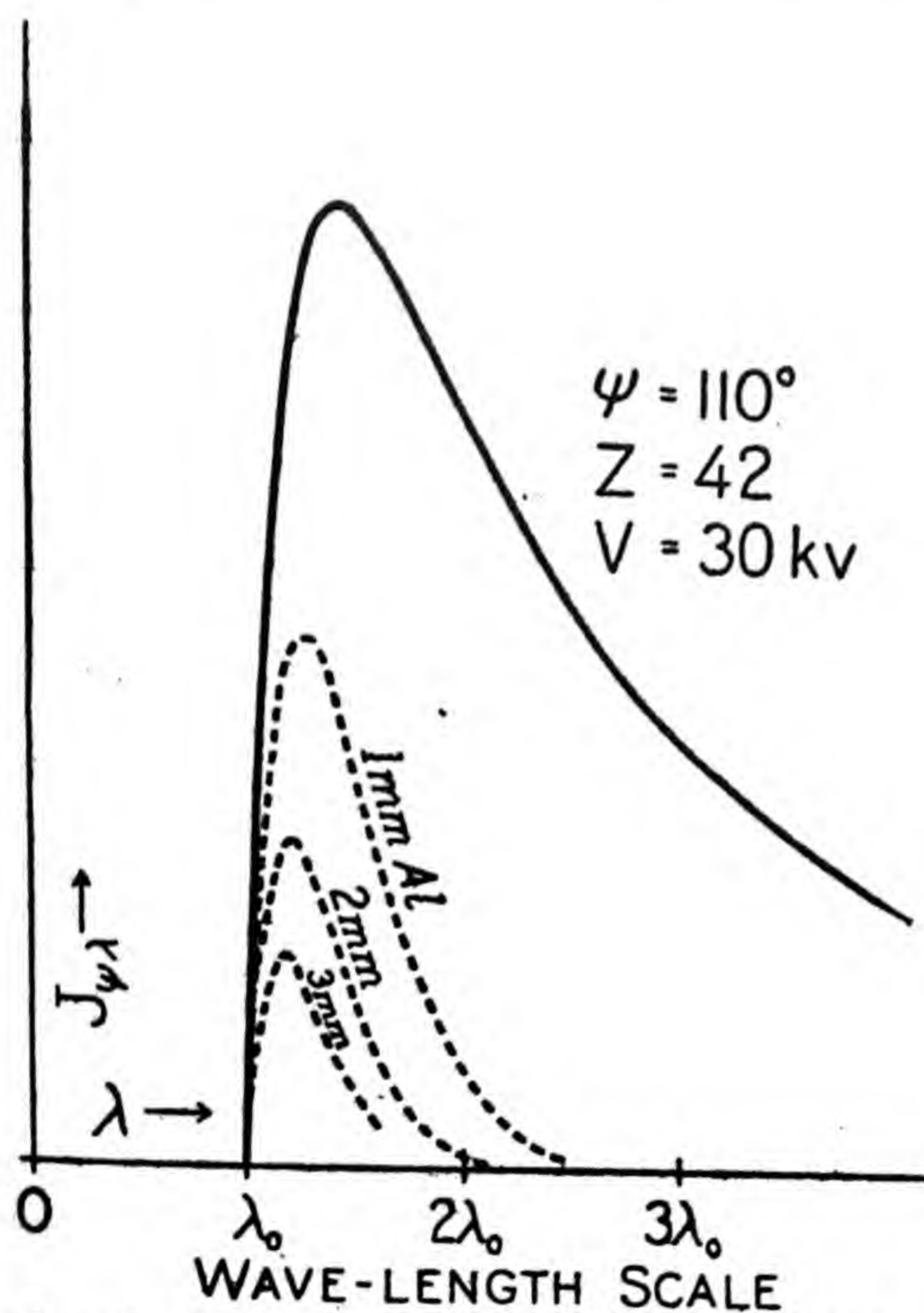


FIG. 18.—Fully corrected wave-length spectrum (181).

This differs from Fig. 17 (q.v.) only in the quantity chosen as abscissa (cf. p. 46).

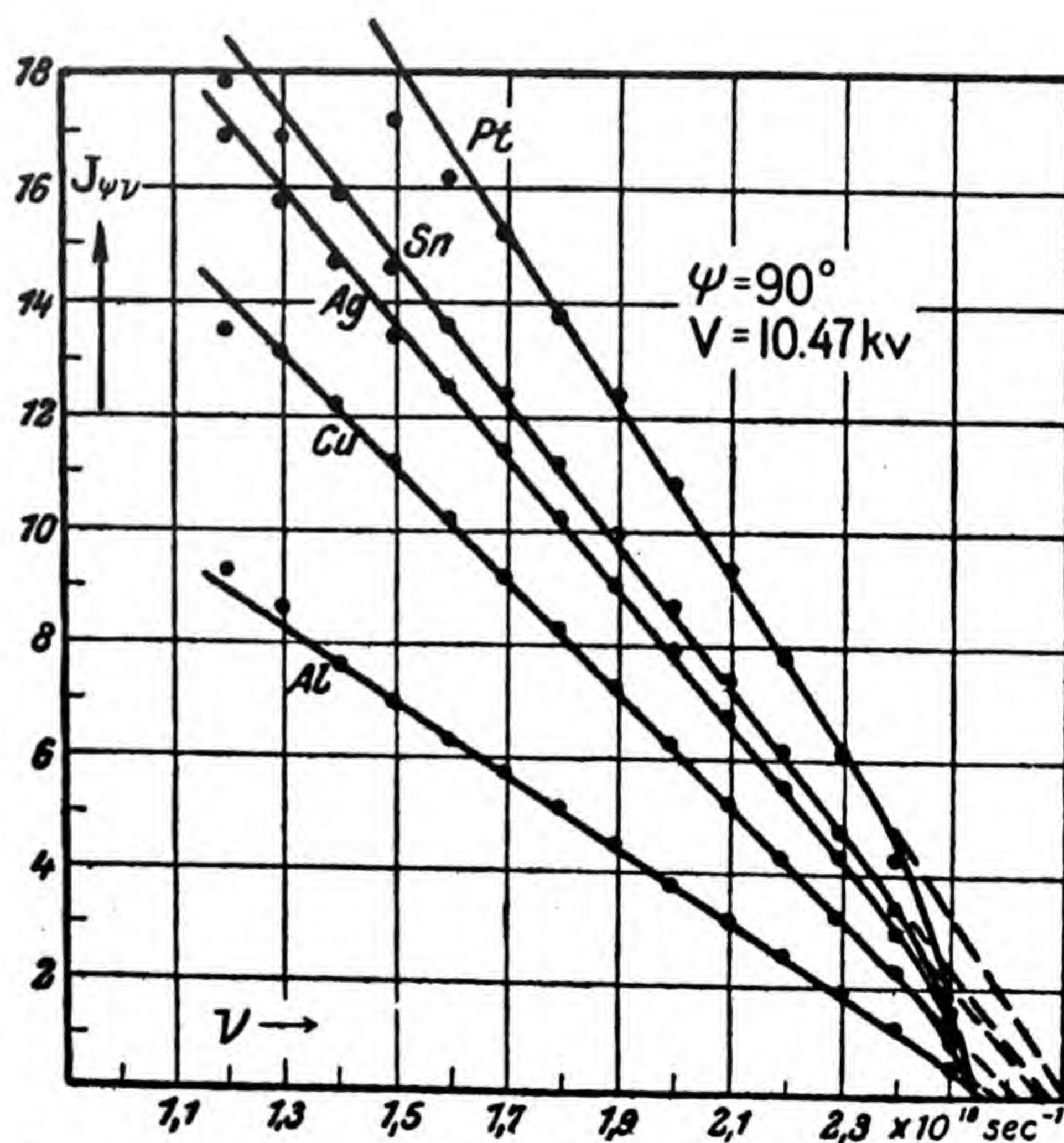


FIG. 20.—Corrected frequency spectrum: Variation with material of target, potential constant (172). (After Siegbahn (142).)

Tube potential and tube current were unvarying and the same for all targets.



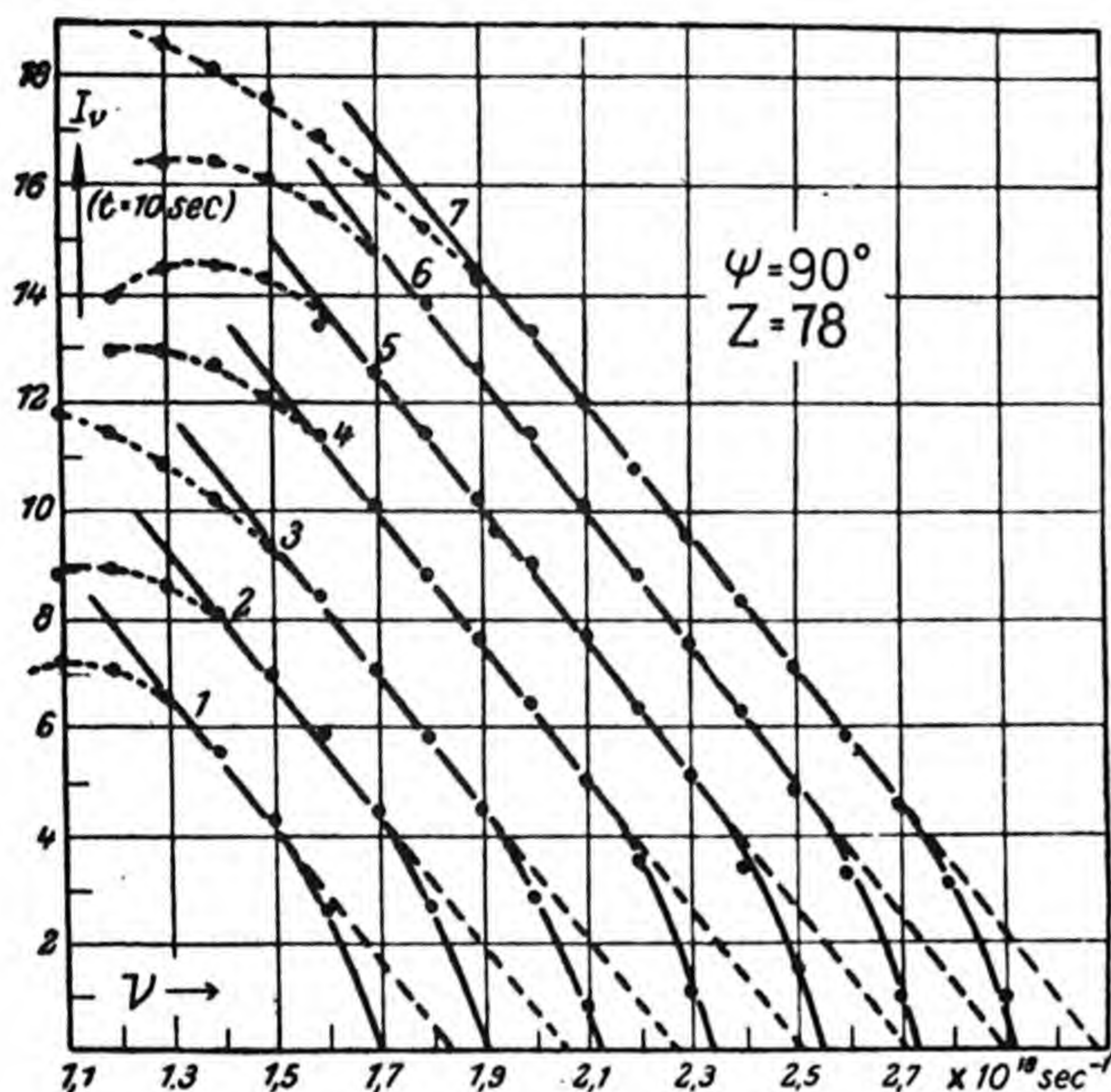


FIG. 21.—Corrected frequency spectrum: Variation with tube potential (172). (After Siegbahn (142)).  
Tube potential unvarying; tube current is the same in all cases.

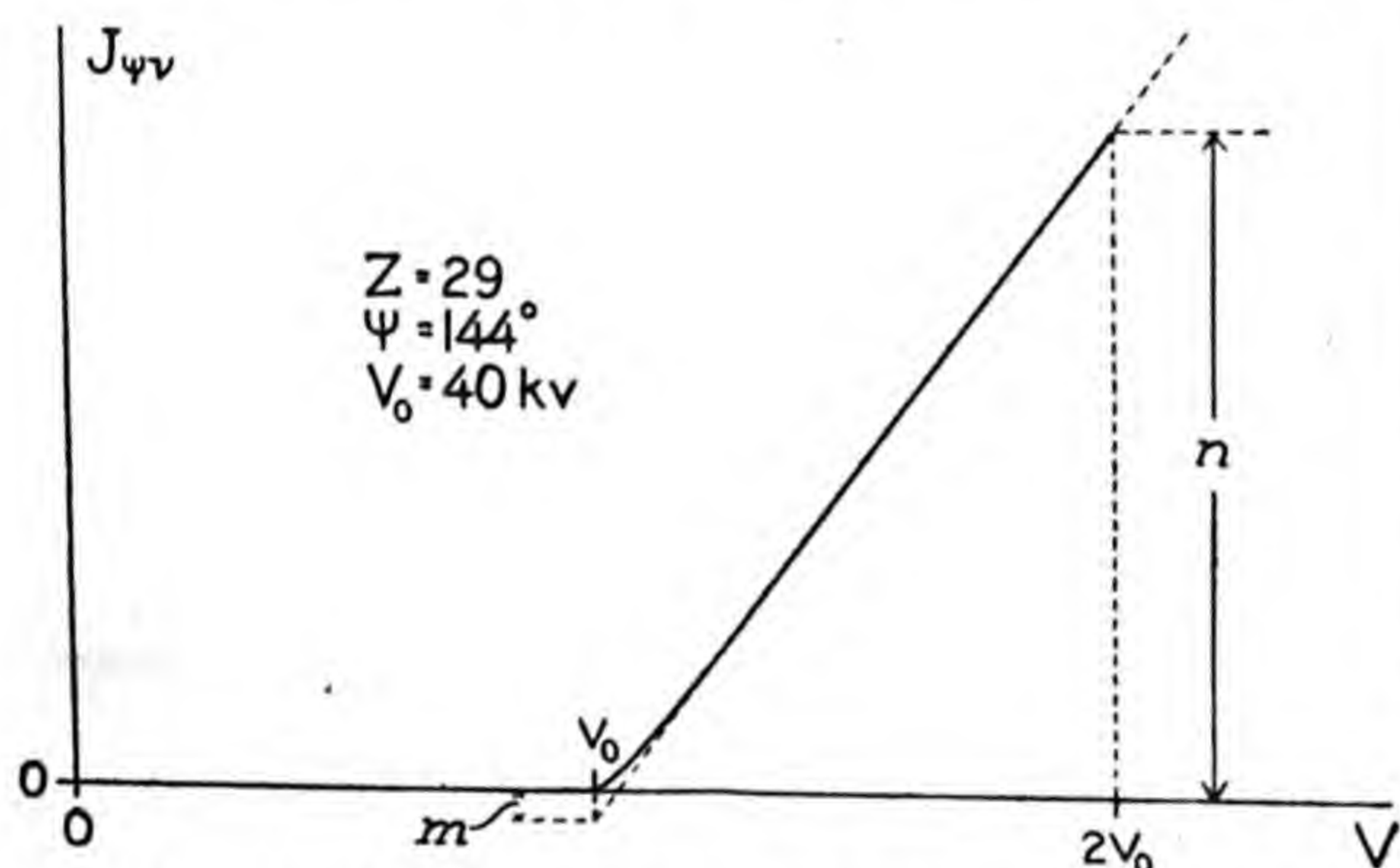


FIG. 22.—An isochromat for Cu ( $Z = 29$ ),  $\psi = 36^\circ$  (126).  
The ratio  $m/n$  is a measure of the  $x$ -term in  $J_{\psi v} = CZ[(\nu_0 - \nu) + x]$ . The data may be transferred to an energy frequency graph by means of the total energy law (126, 177, 186.)

method for measuring X-ray energy seems to be that recently used by Rump in a measurement of unresolved energy (138), but his corrections for absorption may be questioned; when his data are corrected on the basis of other work (126, 185), and stray and characteristic radiation allowed for, they lead to a value for the numerical coefficient ca.  $10 \times 10^{-10}$ ; this is probably the best value available at present. It should be noted that both the above calculations involve the assumption that the formula applies to even the lowest frequencies, of which the energy cannot be measured experimentally owing to absorption in the target and in the walls of the tube.

The most fundamental expression of the laws of X-ray emission will refer to infinitely thin targets, in which the cathode rays have a uniform speed and direction. Such uniformity does not exist in thick targets (185). In them, the cathode rays not only lose speed gradually, until they are completely stopped, but they are also

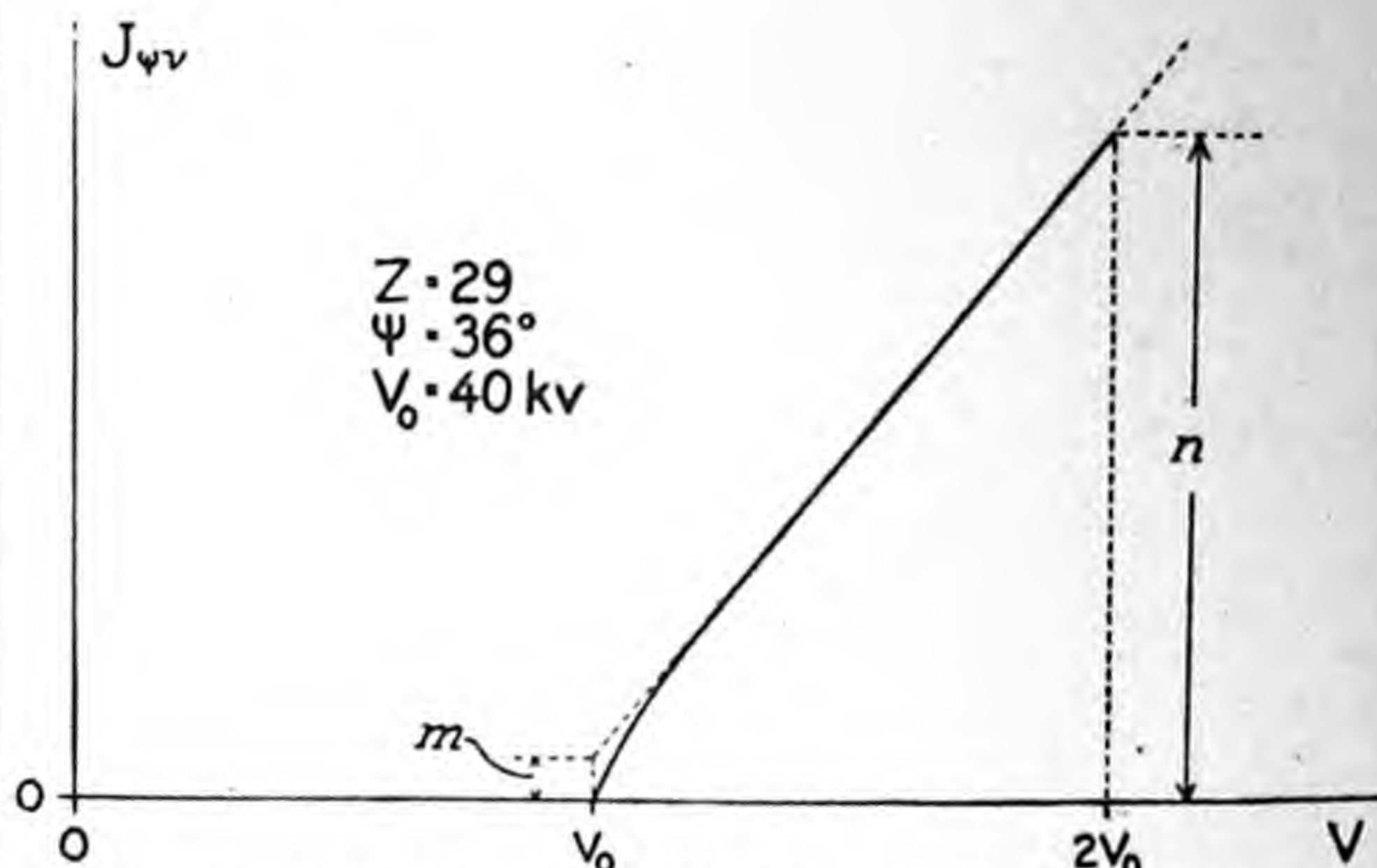


FIG. 23.—An isochromat for Cu ( $Z = 29$ ),  $\psi = 144^\circ$  (126). Differs from Fig. 22 (q.v.) only in value of  $\psi$ .

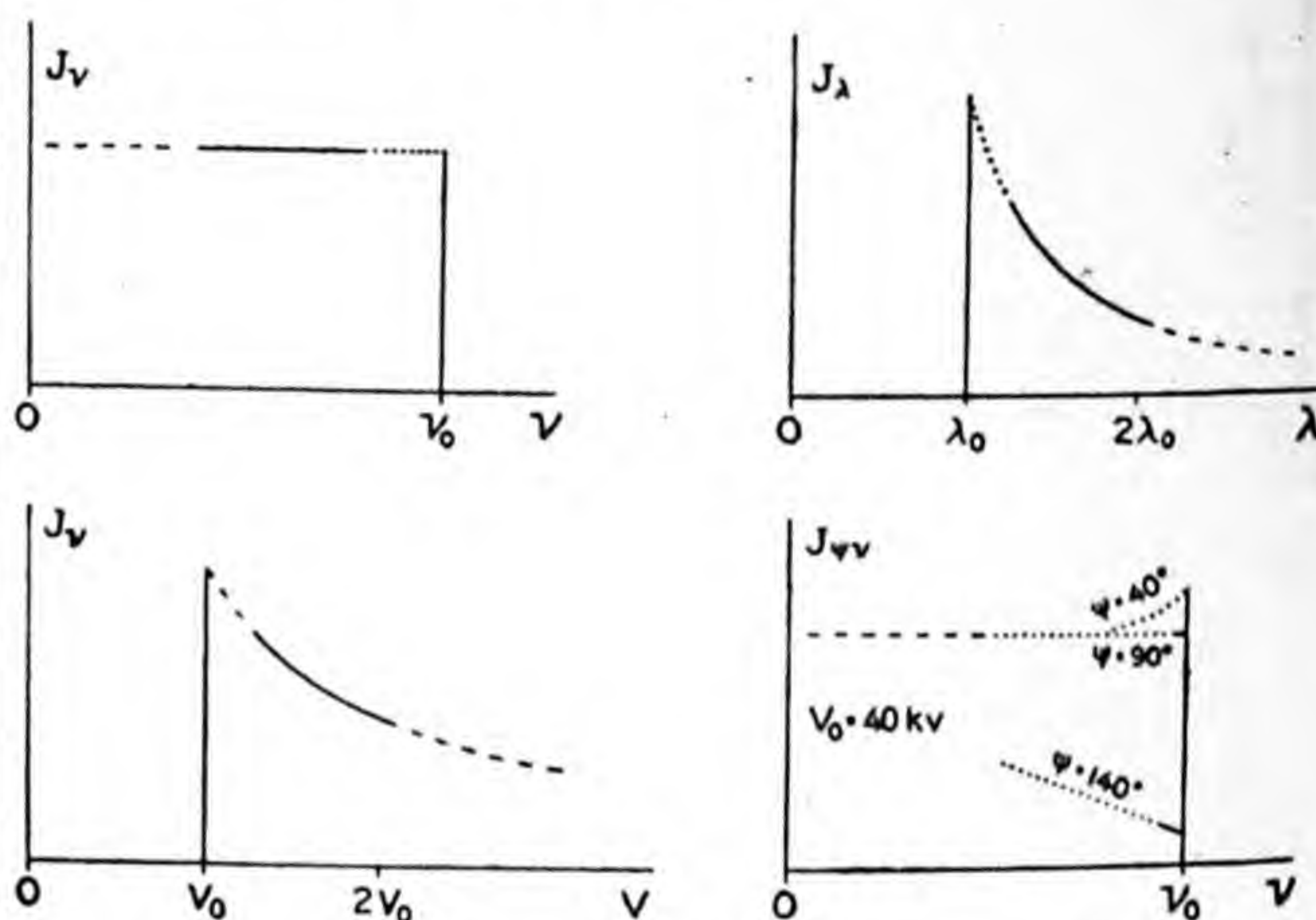


FIG. 24.—Illustrating the continuous spectrum emitted by infinitely thin targets.

Full lines (—) represent data derived from observations with thick targets; dotted lines (....), those from actual thin targets; and broken lines (---) are extrapolations.

deflected by the atoms of the target so that, especially for targets of high atomic numbers, they approach random directions by the time they have lost a small fraction of their original energy; cf. (185). Hence an expression of the thin target intensity as a function of  $\psi$  can be inferred from data for thick targets (126, 176, 186) only if  $(\nu_0 - \nu)$  is much less than  $\nu_0$ ; and an average value of the intensity (summed over all values of  $\psi$ ) can be so inferred only if  $\nu$  is much less than  $\nu_1$ . In this way the full line portions of Fig. 24 were obtained from Nicholas' (126) data, the original interpretation of which was in error. Only unpublished preliminary data for actual thin targets are available, but they confirm the conclusions from thick target data, and, within a rather large experimental error, supplement them as indicated by the dotted lines of the figure.

Of numerous theories that have been proposed (15, 18, 52, 100, 121, 191), only one (100) represents satisfactorily the thin target data. This is based on a "correspondence principle" treatment of radiation from electrons in hyperbolic orbits. Its details have been only partially developed, but it leads to an average intensity (over all values of  $\psi$ ) that agrees with Fig. 24. As applied to thick targets, it leads to the formula here given for the focal spot, but with  $x = 0$ ; and it predicts an efficiency of  $9.2 \times 10^{-10} ZV$ . Predictions based on wave mechanics are not yet in such form as can be tested by experiment.



## LITERATURE

(For a key to the periodicals see end of volume)

- (<sup>1</sup>) Allison, *2*, 30: 245; 27. (<sup>2</sup>) Allison and Armstrong, *2*, 26: 701; 25. (<sup>3</sup>) Allison and Armstrong, *2*, 26: 714; 25. (<sup>4</sup>) Aoyama, Kimura and Nishina, *96*, 44: 810; 27. 46: 150; 27. (<sup>5</sup>) Auger and Dauvillier, *34*, 176: 1297; 23. (<sup>6</sup>) Bäcklin, *96*, 27: 30; 24. (<sup>7</sup>) Bäcklin, *96*, 33: 547; 25. (<sup>8</sup>) Bäcklin, *96*, 38: 215; 26. (<sup>9</sup>) Bäcklin, *243*, 47: 373; 27.
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## REFLECTION AND REFRACTION OF X-RAYS

P. A. ROSS

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Symbols.	Symboles.	Zeichen.	Simboli.	
Refraction of X-rays.	Réfraction des rayons X.	Brechung von Röntgen-Strahlen.	Rifrazione dei raggi X.	49
Reflection of X-rays.	Réflexion des rayons X.	Reflexion von Röntgen-Strahlen.	Riflessione dei raggi X.	50
Variation with temperature.	Variation avec la température.	Änderung mit der Temperatur.	Variazione con la temperatura.	50
Effect of polish.	Effet du poli.	Einfluss der Polierung.	Effetto della pulimentazione.	51
Symbols				
For those not defined here or where used, see Vol. I, p. 16				
$d$	Grating space of the crystal lattice.	$N$	Spectral order.	
$I_{\lambda}$	Ionization produced by monochromatic incident beam.	$n$	Number of electrons per unit volume.	
$I_{\lambda'}$	Ionization produced by monochromatic reflected beam.	$l_1, l_2, l_3$	Direction cosines of reflecting plane with reference to the axes of the crystal.	
$k_0$	Molecular gas constant.	$s$	Length of one edge of the elementary cube of the crystal.	
$m_0$	Mass of the atom.	$\theta$	Glancing angle corresponding to $\lambda$ .	
		$\theta_0$	Glancing angle if $\mu$ were unity. True glancing angle.	



- $\lambda$  Wave-length.  
 $\mu$  Index of refraction.  
 $\nu$  Frequency.  
 $\phi$  Debye's function (13).  
 $\omega$  Angular velocity of the reflecting crystal.

**Refraction.**—Darwin's formula (7) is  $\theta - \theta_0 = (1 - \mu)/(\sin \theta \cos \theta)$ , hence  $\lambda = \{1 - (1 - \mu)/\sin^2 \theta\} (2d \sin \theta)/N$ . From the optical theory of reflection (16),  $1 - \mu = \frac{e^2}{2\pi m} \left( \frac{n_1}{\nu^2 - \nu_1^2} + \frac{n_2}{\nu^2 - \nu_2^2} + \dots \right)$  where  $n_1, n_2, \dots$  are the numbers of electrons, per unit of volume, having natural frequencies  $\nu_1, \nu_2, \dots$ . Usually  $\nu_1, \nu_2, \dots$  are all small as compared with  $\nu$ , then  $1 - \mu = ne^2/2\pi m \nu^2$ .

TABLE 1.—INDEX ( $\mu$ ) OF REFRACTION OF X-RAYS

$\mu = 1 - \delta \times 10^{-6}$ ;  $\delta_0$  = observed;  $\delta_c$  = computed;  $\rho$  = density of refractor; unit of  $\lambda = 1 \text{ \AA} = 10^{-8} \text{ cm}$ ; of  $\rho = 1 \text{ g cm}^{-3}$

Refractor	$\rho$	$\lambda$	$\delta_0$	$\delta_c$	Lit.
Ag..... Silver	10.5	1.279	21.5	19.8	(6)
CaCO <sub>3</sub> ..... Calcite	2.71	0.70783	2.03 ± 0.1	1.91	(14)
		0.70783	1.7 ± 0.5		
FeS <sub>2</sub> ..... Pyrite	5.01	0.63102	2.87 ± 0.2	2.66	(17)
		0.6311	2.82	2.62	(8)
		0.7078	3.33	3.29	(8)
		0.70783	3.35 ± 0.2	2.34	(17)
		1.389	13.2	13.5	(8)
		1.3892	13.2 ± 0.4	13.6	(17)
		1.537	17.6	17.6	(8)
		1.5372	17.6 ± 0.5	17.7	(17)
	Glass	2.52	0.52	0.7	(6)
		1.279	4.2	5.2	(6)
		2.551	0.630	1.22	(15)
			0.708	1.64	(15)
			1.389	6.648	(15)
			1.538	8.125	(15)
			1.750	10.0	(15)
			1.933	12.38	(15)
	Lacquer	1.279	5.1	11.85	(6)

**Reflection.**—The reflectivity depends upon the polish (Table 4) and upon the temperature (Table 3) of the reflecting surface, as well as upon the crystal plane employed.

TABLE 2.—REFLECTIVITY OF ROCK SALT (NaCl) AND CALCITE (CaCO<sub>3</sub>): X-RAYS

$r(10)^{-5} = E\omega/I$  = integrated reflection;  $I$  = intensity of direct beam,  $E$  = ionization current,  $\omega$  = angular velocity of rotation of crystal;  $E\omega$  is independent of  $\omega$ .  $N$  = spectral order, Pl = reflecting plane. Crystal surfaces are polished.

NaCl					CaCO <sub>3</sub>				
Pl	N	$\lambda$	$r$	Lit.	Pl	N	$\lambda$	$r$	Lit.
100	1	0.613	54	(3)	100	1	0.712	8.72	(5)
100	1	0.614	55	(2)	100	1	1.39	7.70	(18)
100	1	0.710	40.3	(5)	100	1	1.54	8.10	(18)
100	1	1.54	27.5	(18)	100	1	1.75	8.07	(18)
100	1	1.93	20	(18)	100	1	1.93	7.88	(18)
100	2	1.54	4.0	(18)	100	2	1.54	0.66	(18)
100	2	1.93	2.9	(18)	100	2	1.93	0.62	(18)

NaCl (2);  $N = 1$ ;  $\lambda = 0.614$ 

Pl	$r$	Pl	$r$	Pl	$r$
100	55	220	3.34	555	0.075
200	10.9	330	0.390	311	0.650
300	2.78	111	4.95	622	1.47
400	0.435	222	18.1	331	0.445
500	0.064	333	0.318	511	0.335
110	0.278	444	1.54	711	0.168

TABLE 2.—(Continued)

NaCl (2); relative reflectivity;  $\lambda = 0.586$ 

Pl	N	1	2	3	4
100		100	18.7	6.25	
110		41	7.05		
111		16.5	24.4	3.1	4.2

TABLE 3.—REFLECTIVITY FOR X-RAYS: VARIATION WITH TEMPERATURE

See also Figs. 1 and 2

Debye (13) finds that the effect of temperature may be represented by the factor  $F$ , where

$$F = e^{-\frac{1}{2} \cdot \frac{h^2}{m k T_0^2} N_2 (l_1^2 + l_2^2 + l_3^2) \frac{T}{T_0} \phi \left( \frac{T}{T_0} \right)}$$

$T$  = absolute temperature and  $T_0$  is a temperature which is characteristic of the crystal. In certain cases,  $r(t_2)/r(t_1) = 1 - a(t_2 - t_1)(10)^{-6}$ , where  $r(t_2)/r(t_1)$  = ratio of reflectivity at temperature  $t_2$  to that at  $t_1$ . Obs. = observed value of  $r(t_2)/r(t_1)$ , Calc. = value calculated by means of factor  $F$ , Pl = reflecting plane,  $N$  = spectral order. Unit of  $\lambda = 1 \text{ \AA} = 10^{-8} \text{ cm}$ ;  $t$  = centigrade temperature, °C.

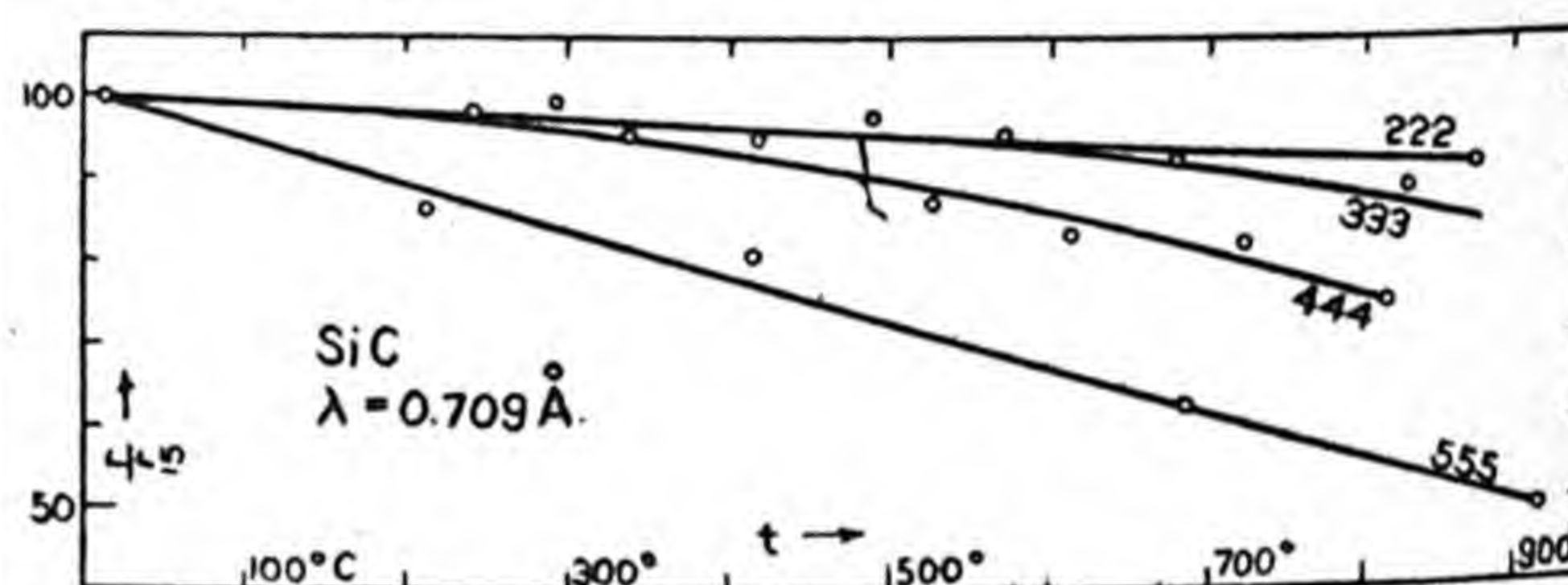


FIG. 1.—Variation of relative reflectivity with temperature: Carborundum (1).

Numbers on curves indicate reflecting planes.

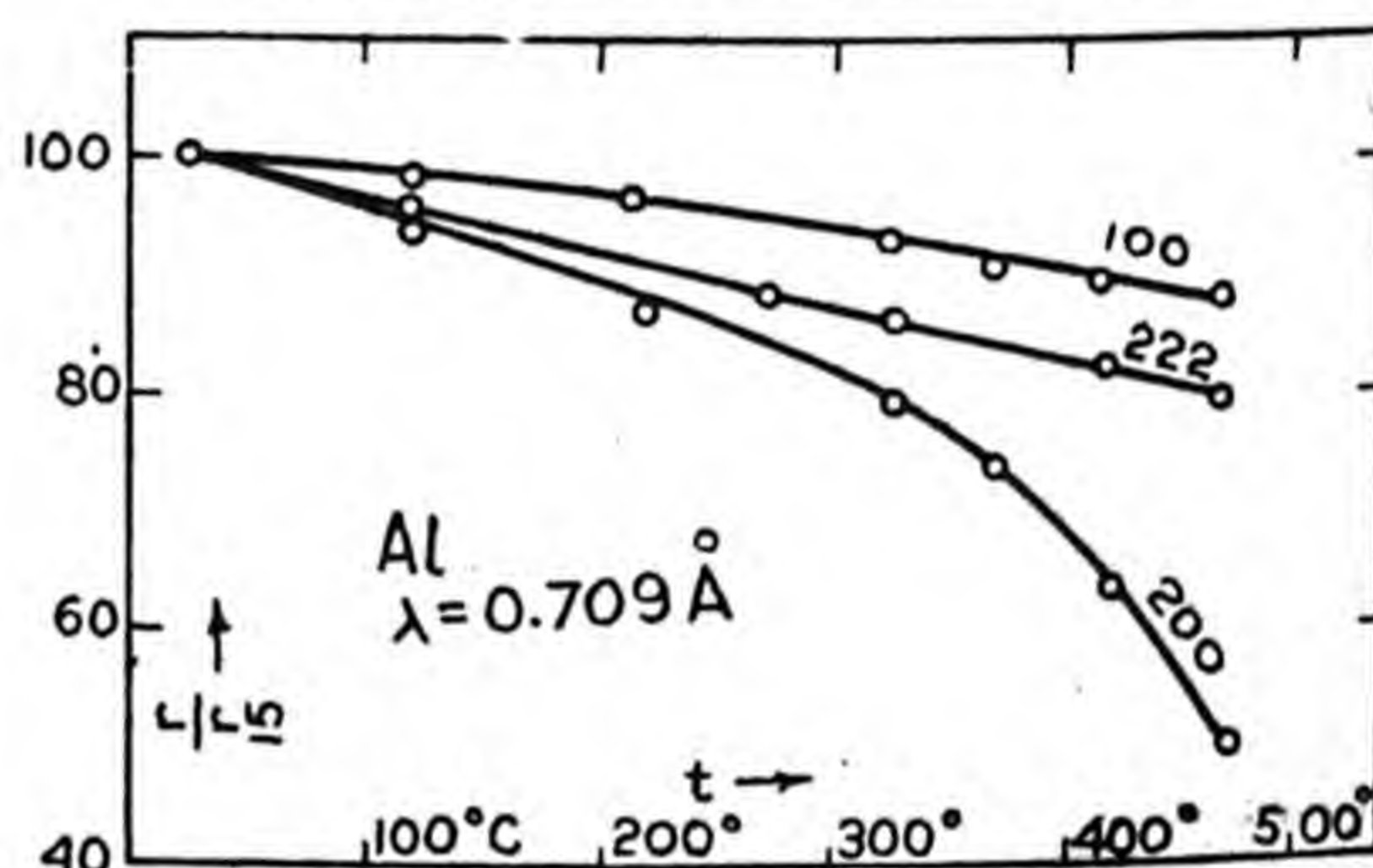


FIG. 2.—Variation of relative reflectivity with temperature: Aluminium (1).

Numbers on curves indicate reflecting planes.

NaCl (2);  $\lambda = 0.614$ ;  $t_1 = 15^\circ$ ;  $t_2 = 370^\circ$  || Al Foil (4);  $\lambda = 0.710$ ;  $N = 1$ ;  $t_1 = 80^\circ$

Pl	N	Obs.	Calc.	Pl	Obs.	Calc.	Obs.	Calc.
100	1	0.934	0.930					
110	1	0.833	0.862	100	0.88	0.966	0.815	0.926
100	2	0.794	0.741	110	0.77	0.935	0.56	0.857
110	2	0.483	0.526	111	0.92	0.973	0.86	0.936
100	3	0.515	0.521	311	0.84	0.913	0.709	0.809

C, Graphite (1);  $\lambda = 0.709$ ; Pl = 0001;  $a = 107$  if  $t_1 = 0^\circ$ ;  $t_1 < t_2 < 900^\circ$ .

Al<sub>2</sub>O<sub>3</sub>, Ruby and sapphire (1);  $\lambda = 0.709$ ;  $t_1 = 15^\circ$ ;  $t_1 < t_2 < 950^\circ$ ;  $a_{110} = 52.6$ ;  $a_{220} = 269$ ;  $a_{222} = 309$ ;  $a_{111} = 373$ ;  $a_{333} = 426$ . Subscripts indicate Pl.



TABLE 4.—REFLECTIVITY OF X-RAYS: EFFECT OF POLISH

Double spectrograph and successive reflections from two crystals.  $r = 100 I_2/I_1$ , where  $I_1[I_2]$  = intensity of beam incident upon [reflected by] the second crystal when so placed that the reflection is a maximum. First order reflection from planes 100 (cf. Fig. 3).  $r_p[r_u]$  = value of  $r$  when crystals are polished [unpolished]. Unit of  $\lambda = 1 \text{ \AA}$ .

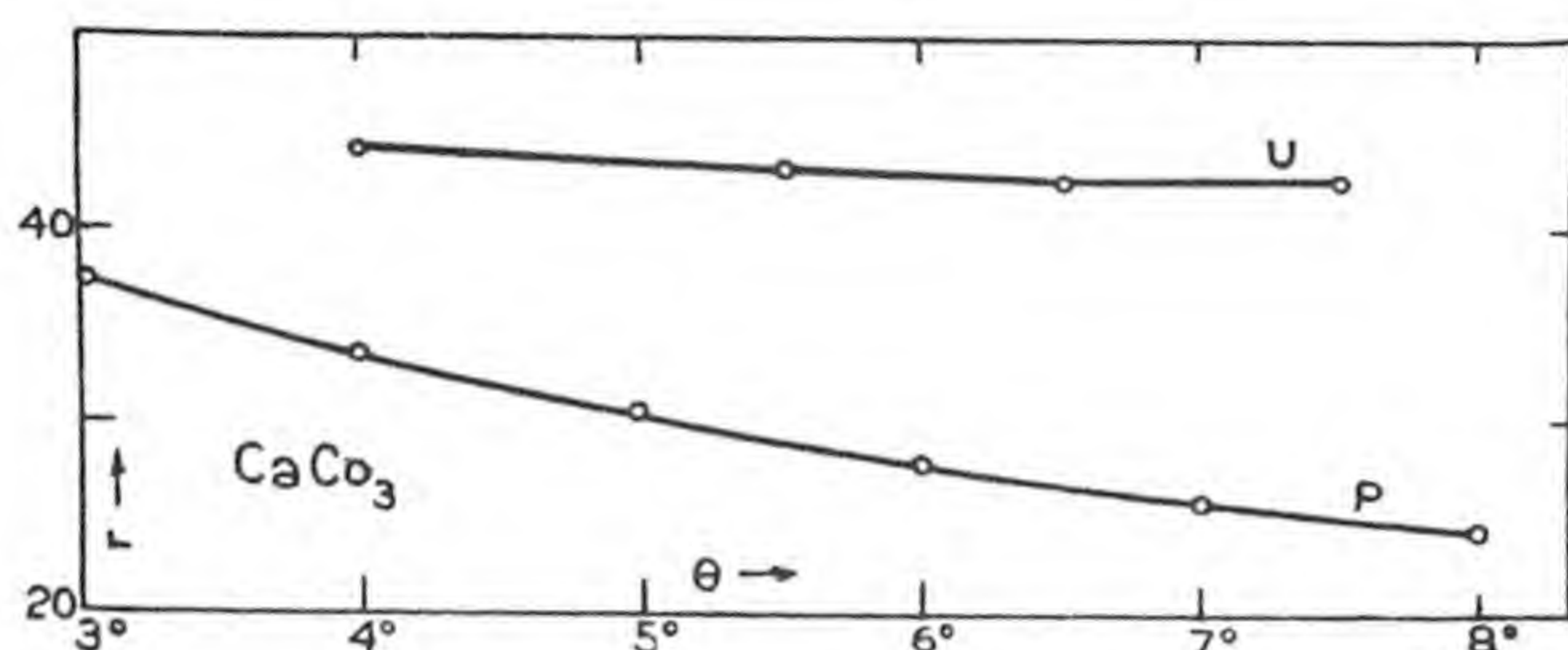


FIG. 3.—Effect of polishing: Calcite (9).

$r$  = % reflected at glancing angle  $\theta$ ;  $P$  = polished;  $U$  = unpolished.  $\lambda = 0.317$  to  $0.842 \text{ \AA}$ ,  $P_1 = 100$ . (Cf. Table 4.)

TABLE 4.—(Continued)

$\lambda$	$r_u$	$r_p$	Lit.
<b>CaCO<sub>3</sub>, Calcite</b>			
0.369		35.4	(9)
0.422	44.4		(9)
0.580	43.1	29.2	(9)
0.685	42.8		(12)
0.790		25.3	(12)
<b>NaCl, Rock salt</b>			
0.294	24.8	22.1	(10)
0.491	15.3	15.1	(10)
0.686	13.0	11.5	(12)

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## ELECTRONICS AND GAS CONDUCTION

## COMPLETE INDEX

Electric arcs.  
Thermal emission of electrons.  
Contact potentials.  
Current flow in vacuum tubes with hot cathodes.  
Emission of secondary electrons.  
Photoconductivity and photo-emf.  
Photoemission of electrons.  
Critical potentials of atoms and molecules.  
High voltage corona.  
Properties of carriers of free electricity in gases.  
Ionization of gases.  
Electric conductivity of flames.

## INDEX COMPLET

Arcs électriques.  
Émission thermique des électrons.  
Potentiels de contact.  
Passage du courant dans les tubes à vide avec cathodes chaudes.  
Émission d'électrons secondaires.  
Photoconductivité et photo-fem.  
Photoémission des électrons.  
Potentiels critiques des atomes et molécules.  
Décharge en couronne.  
Propriétés des porteurs d'électricité libre dans les gaz.  
Ionisation des gaz.  
Conductivité électrique des flammes.

## GESAMT INDEX VERZEICHNIS

Elektrischer Lichtbogen.  
Thermische Elektronenemission.  
Kontaktpotentiale.  
Stromfluss in Vakuumröhren mit heissen Kathoden.  
Emission sekundärer Elektronen.  
Photoelektrische Leitfähigkeit und photoelektromotorische Kraft.  
Photoemission der Elektronen.  
Kritische Potentiale der Atome und Moleküle.  
Hochspannungskorona.  
Eigenschaften von Trägern freier Elektrizität in Gasen.  
Ionisation der Gase.  
Elektrische Leitfähigkeit von Flammen.

## INDICE COMPLETO PAGE

Archi elettrici..... 51  
Emissione termica di elettroni..... 53  
Potenziali di contatto..... 56  
Flusso di corrente in tubi vuoti a catodo caldo.... 58  
Emissione di elettroni secondari..... 60  
Fotoconduttività e foto-fem..... 66  
Fotoemissione di elettroni..... 67  
Potenziali critici di atomi e molecole..... 69  
Corona ad alto potenziale..... 107  
Proprietà dei portatori di elettricità libera nei gas..... 110  
Ionizzazione dei gas..... 119  
Conducibilità elettrica delle fiamme..... 156

## ELECTRIC ARCS

C. D. CHILD

## CONTENTS

	PAGE
Symbols.....	51
Electrical data.....	51
Mechanical data.....	52
Temperature of the arc.....	52
Photometric data.....	52

## SYMBOLS

$D$  Diameter of electrodes.  
 $E$  Strength of electric field.  
 $I$  Electric current.  
 $l$  Length of arc.

$R$  True resistance of arc:  $R$  = limiting values of  $dV/dI$  as  $dI$  approaches zero.  
 $T$  Absolute temperature.  
 $vp$  Vapor pressure.  
 $V$  Voltage difference of electrodes.

**Electrical Data.**—The residual emf between cored carbon electrodes, after removal of impressed emf, is  $\geq 0.64$  volt at 0.4 sec and 0.05 volt at 7 sec (3). Duddell defines the counter emf as  $V - RI$ ; for carbon arcs, he finds it varies from 11.2 to 18.5 volt, depending upon the current and the nature of the electrode (5, 10). Others have defined the term in various ways; hence the recorded values vary greatly (5).



## VOLTAGE DIFFERENCE: EFFECT OF LENGTH AND CURRENT

$V = a + bl + cI^{-1} + dI^{-1}$ . Carbon (C) electrodes are solid unless the contrary is indicated. For metallic electrodes,  $I$  small, see (8). Unit of  $V = 1$  volt, of  $I = 1$  ampere, of  $l = 1$  mm.

Electrodes	Gas	a	b	c	d	$I$	Lit.
Carbon*	Air	38.88	2.07	11.66	10.54	3 to 16	(2)
Carbon†	Air	0.0	0.99	0.0	0.0	120 to 700	(33)
Carbon‡	Air	62	11.4	0.0	3.26	3	(12)
Carbon	CO <sub>2</sub>	80	1.17	90	7.3	3	(12)
Carbon	H <sub>2</sub>	0.0	29	180	22.2	3	(12)
Carbon	H <sub>2</sub> O	200	1.0	0.0	18.5	3	(12)
Carbon A. C. §		20.4	1.81	0.0	0.0	6.5	(15)
Magnetite	Air	35.8	0.89	-7	5.81	3	(12)
Copper		18	17.5	52.1	3.43		(28)

\*  $D = 11$  mm;  $l$  measured from tip of cathode to plane through edges of crater; for long arcs,  $V$  is less than value given by these constants (10). For flaming arcs (6) and for cored carbons (20, 21),  $V$  is less than for solid carbons; no simple equation can be given for cored carbons (32).

†  $l$  measured from tip of cathode to bottom of crater.

‡  $l \leq 50$  cm.

§ Cored electrodes; A. C. = alternating current arc. See also note.\*

|| For metal electrodes,  $V$  varies greatly (6).

## DISTRIBUTION OF VOLTAGE

Determined by use of exploring electrodes. For small currents between metallic electrodes, see (8).  $V_a[V_c]$  = drop of potential at anode [cathode]; anode = electrode of higher potential. Unit of  $V_a, V_c = 1$  volt; of  $E = 1$  volt/cm; of  $I = 1$  ampere.

Electrode	Gas	$V_a$	$V_c$	$E$	$I$	Lit.
C, Carbon*	Air	33.7	8.96		10	(2)
Hg	Vacuum	4.08†	5.27 (27)	0.68†	4.3	
Na-K	Vacuum	2.5	3.8	0.8	1.5	(23)

\* Solid electrodes;  $l = 5$  mm.

†  $vp = 0.45$  mm Hg; value of  $V_a$  varies from 4.8 to 18, depending upon  $vp, I$ , and the shape of tube and electrodes (13); as  $vp$  and  $I$  are increased indefinitely  $V_a$  approaches 3.72 as limiting value (12, 24).

‡  $vp = 2$  mm Hg,  $T = 1000^\circ\text{K}$  (2).

**Mechanical Data.**—Area of crater =  $1.34 \text{ mm}^2$  per ampere for solid carbons (1); =  $(3.83 + 1.52I) \text{ mm}^2$  for positive carbon cored, negative solid, and  $l = 4$  mm, unit of  $I = 1$  ampere (2).

Area of cathode spot =  $0.0253 \text{ mm}^2$  per ampere for Hg-arcs (14); =  $0.213 \text{ mm}^2$  per ampere for C-arcs of such lengths that anode does not affect the area and for  $I = 1.5$  to 10 ampere (14).

Consumption of electrodes (unit of  $l = 1$  mm). Solid carbons, open arcs,  $D = 1$  cm, anode consumption if  $l \geq 20$  mm is  $(2.4 + 1.3I + 0.0044I^2)$  g per hr if  $I = 4$  ampere, and  $(1.73 + 0.086I + 0.003I^2)$  g per hr if  $I = 8$  ampere; cathode consumption if  $l \geq 12$  mm,  $I = 6$  ampere, is  $(0.72 + 0.022I - 0.0115I^2)$  g per hr (11).

Solid carbons, enclosed arcs,  $D = 11$  mm,  $I = 5$  ampere, consumption of positive electrode =  $1.65 \text{ mm per hr}$ , of negative electrode =  $0.319 \text{ mm per hr}$  (21).

Flaming arc, carbon electrodes, anode  $D = 8$  mm, cathode  $D = 7$  mm, each electrode consumption =  $30 \text{ mm per hr}$  (26).

Magnetite arc, cathode consumption =  $1.5 \text{ mm per hr}$  (16),  $I = 6.6$  ampere, value of  $D$  is not stated.

**Temperature of the Arc.**—The temperature of the cathode is usually several hundred degrees lower than that of the crater; that of the gases between the terminals is higher than that of the crater; the exact value is not known. The temperature of the crater of the carbon arc in air is between  $3900$  and  $4000^\circ\text{K}$  for graphite terminals (30);  $4200^\circ\text{K}$  at 1 atm., decreasing to  $3940^\circ\text{K}$  at 0.1 atm. for solid carbons (18, 19);  $4200^\circ\text{K}$  at 1 atm; increasing to  $5890^\circ\text{K}$  at 22 atm. for impregnated (cored) carbons (18, 19).

## PHOTOMETRIC DATA FOR ARCS

The luminous efficiency of the radiation (= ratio of energy of luminous radiation to that of total radiation) varies with  $l$  and  $I$  from 0.043 to 0.083 for direct current enclosed arcs between solid carbons, and from 0.115 to 0.225 for yellow flaming arcs, direct and alternating current (17).

$V_t$  = voltage difference of lamp terminal;  $W$  = power expended, in lamp;  $scp$  = mean spherical candlepower,  $lcp$  = mean lower hemispherical candle-power. Unit of  $I = 1$  ampere; of  $V_t = 1$  volt; of  $W = 1$  watt; of  $scp, lcp = 1$  candle.

Type	$I$	$V_t$	$W$	$scp$	$W/scp$	$lcp$	$W/lcp$	Lit.
Direct current arcs								
Carbon, open	9.6	50	480	540	0.89	813	0.59	(25)
Carbon, enclosed	6.6	70 to 75	480	310	1.55	505	0.95	(25)
Flaming	8	44.2*	354	919	0.385	1670	0.21	(26)
Magnetite†	5	77.5	388	426	0.91			(9)
Alternating current arcs								
Carbon, enclosed	6.6	70	455	314	1.44			(22)
Flaming (Blondel)	10	35*	255	1890	0.135			(4)

\* Voltage difference of electrodes.

† With clear globe and small internal reflector.

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Table 1.—(Continued)

Symbol	$a_1$	$n$	$\beta_1$	$a_2$	$n$	$\beta_2$	$\phi_2$	$i_T$	$n$	$T, ^\circ K$	Lit.
Elementary substances.—(Continued)											
Pt.—(Continued).....	3.02	3	4.60	1.36	-2	4.40	3.87	4.5	-8	1600	(25)
	9.90	3	5.20	4.46	-2	5.00	4.31	2.9	-9	1600	(25)
				3.01	1	4.85	4.18				(29, 35)
	9.3	6	6.32	2.88	1	6.06	5.22	3	-9		(33)
	7.59	8	5.79	Not gas-free§			4.99				(35)
	1.21	7	5.31	Less gas§			4.57				(35)
	9.7	8	5.84	In hydrocarbon vapors							(25)
Ta; see also Table 2.....			4.98	6.02	1	4.72	4.97	1.38	-2		(10)
	4.3	2	4.42	1.31	-3	4.17	3.58	4	-6	2000	(6, 28)
	1.12	7	5.00	3.40	1	4.70	4.04	8.9	-3		(19, 28)
	8.32	6	5.08	2.95	1	4.85	4.18	3.2	-3		(33)
	1.19	5	3.64	Not gas-free§			3.14				(35)
	3.61	4	3.64	Less gas§			3.14				(35)
Th.....				6.02	1	3.89	3.35	4.3	-3	1600	(43)
Th on W†; see also Tables 2 and 4.....				3.0	0	3.05	2.63	4.0	-2	1600	(9*)
				7.0	0	3.12	2.69				(16, 23)
U on W†.....				3.2	0	3.30	2.84	9.1	-3	1600	(8)
W; see also Tables 2, 3, and 4.....				6.02	1	5.240	4.52	1.00	-3	2000	*
	1.05	7	5.51	6.02	1	5.236	4.52	1.00	-3	2000	(4)
			5.30	4.36	1	5.100	4.40	1.45	-3	2000	(33)
			5.53	6.02	1	5.250	4.53	9.1	-4	2000	(10)
			5.77	6.02	1	5.225	4.50	1.12	-3	2000	(42, 43)
Yt on W†.....				7.0	0	3.13	2.70	5.8	-2	1600	(8)
Zr.....				3.00	3	5.22	4.50	5.50	-2	2000	(43)
Zr on W†.....				5.00	0	3.65	3.15	1.59	-3	1600	(7)
Oxides on Pt											
Al <sub>2</sub> O <sub>3</sub> .....	6.61	6	4.85	1.62	1	4.63	3.90	5.9	-2	2200	(33*)
	6.40	0	3.73	2.09	-5	3.48	3.00	6.2	-7	1873	(14)
B <sub>2</sub> O <sub>3</sub> .....	5.37	6	5.45	1.32	1	5.23	4.51	3.1	-3	2200	(33*)
BaO.....	6.6	5	2.15	2.88	0	1.95	1.68	3.55	-1	1200	(33*)
	7.16	7	4.3			4.12					(37)
	4.70	7	4.16	2.72	2	3.99	3.44	2.78	-6	1223	(14)
BaO + SrO.....	8	4	1.94			1.76	1.51	2.7	-1		
	2.4	5	2.38			2.20	1.89	2.03	-3	1200	(1*)
	In O <sub>2</sub> , $P = 0.005$ mm			1.07	-3	1.21		6.45	-2	1200	(18)
BeO.....	8.3	7	4.77	4.27	3	3.59					(18)
	1.03	0	2.39	3.60	2	4.57	3.94	1.78	-1	2000	(33*)
CaO.....	2.05	7	3.12	4.56	-6	2.19	1.88	1.03	-6	1373	(14)
	1.11	8	4.5	1.29	2	2.92	2.52	2.19	-1	1400	(33*)
	6.36	11	4.8			4.33					(37)
	1.75	7	4.3			4.62					(13)
	4.30	7	4.03	2.49	2	3.86	3.33	1.83	-6	1173	(14)
CdO.....	3.7	-1	3.02	1.65	-6	2.82	2.43	2.2	-7	1673	(14)
CeO <sub>2</sub> .....	1.95	3	3.71	8.62	-2	3.51	3.02	2.01	-6	1523	(14)
Co <sub>2</sub> O <sub>3</sub> .....	6.67	3	4.97	2.17	-2	4.72	4.06	6.5	-7	1723	(14)
CuO.....	3.5	-3	2.25	1.55	-8	2.05	1.76	2.2	-7	1673	(14)
Fe <sub>2</sub> O <sub>3</sub> .....	3.57	3	4.69	1.16	-2	4.44	3.82	2.3	-7	1723	(14)
La <sub>2</sub> O <sub>3</sub> .....	6.9	2	3.79	3.03	-3	3.59	3.10	2.01	-6	1623	(14)
MgO.....	2.34	8	4.04	1.02	+3	3.84	3.31	1.02	-1	1600	(33*)
	3.37	0	3.95	1.10	-5	3.70	3.19	1.0	-7	1873	(14)
NiO.....	2.79	4	5.12	9.1	-2	4.87	4.19	1.5	-7	1723	(14)
Sc <sub>2</sub> O <sub>3</sub> .....	5.50	6	4.31	1.35	1	4.09	3.52	7.2	-2	2000	(33*)
SiO <sub>2</sub> .....	3.80	6	5.74	1.23	1	5.50	4.75	8.5	-4	2200	(33*)
SrO.....	9.3	5	2.36	4.07	0	2.16	1.86	8.5	-2	1200	(33*)
	5.07	7	4.49	2.58	2	4.30	3.71	8.7	-7	1273	(14)
	7.5	2	1.41	Anode potential = 200 volt							(11)
	2.4	3	1.44	Anode potential = 300 volt							(11)
ThO <sub>2</sub> .....	1.78	5	3.93	5.7	-1	3.69	3.18	2.3	-2	2000	(33*)
	3.5	1	3.56	1.54	-4	3.36	2.89	2.1	-7	1573	(14)
TiO <sub>2</sub> .....	6.31	5	5.16	2.04	0	4.92	4.24	1.2	-3	2200	(33*)



TABLE 1.—(Continued)

Symbol	$a_1$	$n$	$\beta_1$	$a_2$	$n$	$\beta_2$	$\phi_2$	$i_T$	$n$	$T, ^\circ\text{K}$	Lit.
Oxides on Pt.—(Continued)											
$\text{Yt}_2\text{O}_3$	6.03	6	3.82	1.48	1	3.60	3.10	1.00	— 1	1800	(33*)
	1.86	4	3.63	8.22	— 2	3.43	2.95	2.36	— 6	1373	(14)
$\text{ZnO}$	3.1	— 1	3.51	1.0	— 6	3.26	2.81	2.6	— 7	1973	(14)
$\text{ZrO}_2$	1.17	6	4.65	3.80	0	4.41	3.80	4.2	— 3	2000	(33*)
	6.57	3	3.66	2.90	— 2	3.46	2.98	1.71	— 6	1423	(14)

Oxides on 95% Pt + 5% Ni (3)

Electrical resistivity of core =  $2.2(10)^{-5}(1 + 0.00208t - 4.6(10)^{-7}t^2)$  ohm cm,  $t$  is centigrade temperature,  $^\circ\text{C}$ . The coating is a mixture of the oxides of Ba and Sr plus a small admixture of Ni (and Pt) which is transferred from core to coating during preparation and activation of the filament. Thermal emissivity (ratio to black-body) =  $0.4 + 2.5(10)^{-4}T$  if  $800^\circ\text{K} < T < 1200^\circ\text{K}$ . Electron emission in zero field is given by  $I_T = (10)^{-2}T^2e^{-11600/T}$  ampere/cm<sup>2</sup>. For anode potential = 150 volt and space-charge limited current = 0.010 ampere/cm<sup>2</sup>, the average life is  $1.5(10)^{-5}e^{22000/T}$  hr. The following values are those most probable when anode potential = 150 volt and electric field is zero:

$T$	900	950	1000	1050	1100	$^\circ\text{K}$
$I_T$	20	45	90	170	310	$10^{-3}$ ampere/cm <sup>2</sup>
$p_r$ †	2.3	3.0	3.7	4.6	5.6	watt/cm <sup>2</sup>
$p_e$ ‡	0.02	0.045	0.09	0.17	0.31	watt/cm <sup>2</sup>
Life	730**	170**	55	20	7.4	$10^3$ hr

\* This value is especially good. † Monatomic layer.

‡ Emission is a function of bulb temperature; bulb at  $30^\circ\text{C}$ .

§ These data are not very reliable.

|| Values on this line should not be used if  $T > 1600^\circ\text{K}$ .¶  $p_r$  = power thermally radiated;  $p_e$  = power absorbed by electron emission.

\*\* Computed.

TABLE 2.—ELECTRON EMISSION FROM MO, TA, TH ON W, AND W:  
VARIATION WITH TEMPERATURE

Electric field is assumed zero; if, at cathode,  $dV/dr > 0$ , a correction must be applied, see (31); correction must be applied for losses in the leads, see (41).  $I = i \times 10^a$  = current per unit area =  $A_2T^2e^{-b_2/T}$  ampere/cm<sup>2</sup>.

$T, ^\circ\text{K}$	Mo		Ta		Th on W		W	
	$i$	$n$	$i$	$n$	$i$	$n$	$i$	$n$
1 000	3.24	-15	1.95	-13	1.73	-7	1.07	-15
1 100	4.09	-13	1.71	-11	3.31	-6	1.52	-13
1 200	2.33	-11	7.21	-10	3.95	-5	9.73	-12
1 300	7.36	-10	1.73	-8	3.27	-4	3.21	-10
1 400	1.41	-8	1.23	-7	2.03	-3	6.62	-9
1 500	1.91	-7	2.89	-6	1.00	-2	9.14	-8
1 600	1.89	-6	2.44	-5	4.06	-2	9.27	-7
1 700	1.38	-5	1.51	-4	1.40	-1	7.08	-6
1 800	8.32	-5	7.94	-4	4.28	-1	4.47	-5
1 900	4.14	-4	3.61	-3	1.164	0	2.28	-4
2 000	1.74	-3	1.38	-2	2.864	0	1.00	-3
2 100	6.61	-3	4.62	-2			3.93	-3
2 200	2.14	-2	1.41	-1			1.33	-2
2 300	6.58	-2	3.92	-1			4.07	-2
2 400	1.81	-1	1.00	0			1.16	-1
2 500	4.62	-1	2.38	0			2.98	-1
	$A_2 = 60.2$		$A_2 = 60.2$		$A_2 = 3.0^*$		$A_2 = 60.2$	
	$b_2 = 51\ 300$		$b_2 = 47\ 200$		$b_2 = 30\ 500^*$		$b_2 = 52\ 400$	

\* These values should not be used for computing the emission of Th on W at  $T > 1600^\circ\text{K}$ , approx.; see Table 4.

TABLE 3.—ELECTRON EMISSION BY W: EFFECT OF GASES (19, 28)

For effect of gas on other substances, see Table 1;  $I = A_1T^{1/2}e^{b_1/T}$  ampere/cm<sup>2</sup>;  $A_1 = a_1 \times 10^a$ ,  $b_1 = \beta_1 \times 10^4$ ;  $P$  mm of Hg = pressure of the gas.

Gas	$P$	$a_1$	$n$	$\beta_1$
Vacuum	0.00007	1.62	— 2	5.55
$\text{H}_2$	0.012	2.58	+ 2	8.25
	0.007	3.63	9	11.5
	0.0017	3.67	7	10.5
	0.0005	2.05	3	8.5

TABLE 2.—(Continued)

Gas	$P$	$a_1$	$n$	$\beta_1$
$\text{O}_2$		3.25	4	9.43
$\text{N}_2^*$	0.002	1.05	1	7.32
		7.95	— 1	6.82

\* Effect for  $\text{N}_2$  varies with anode voltage.

TABLE 4.—EMISSION OF ELECTRONS BY THORIATED W (9)

When W containing Th is heated, there is evaporation of Th from the surface and a diffusion of Th from the interior to the surface (see Table 5); the equilibrium condition is determined by the balancing of these two effects. If we write  $\theta = (b_\theta - b_W)/(b_{\text{Th}} - b_W)$ , where  $b_{\text{Th}}$  is the maximum value of  $b_2$  for thoriated W, and  $b_W$  and  $b_\theta$  are, respectively, the values of  $b_2$  for W and for the thoriated W under study, then  $\theta$  is, effectively, the fraction of the surface which is completely covered with Th. At temperatures above ca.  $1600^\circ\text{K}$ , the equilibrium value of  $\theta$  is  $< 1$ , and decreases as  $T$  increases (21). Kingdon (16, 23) states  $b_\theta = 31\ 200\theta + 52\ 200(1 - \theta)$  and  $A_2 = [7^\theta + 60^{(1-\theta)} - 1]$  ampere/(cm<sup>2</sup> deg<sup>2</sup>).  $I_T = A_2T^2e^{-b_2/T}$  ampere/cm<sup>2</sup> =  $i \times 10^a$ ;  $b_2 = \beta_2 \times 10^4$ .

$\theta$	$\log_{10} A_2$	$\beta_2$	$\log_{10} I^*$	$i^*$	$n$
1	0.455	3.040	0.066	1.16	0
0.924	0.397	3.213	1.613	4.19	— 1
0.830	0.318	3.415	1.072	1.18	— 1
0.723	0.573	3.657	2.775	5.96	— 2
0.565	0.890	4.007	2.292	1.96	— 2
0.440	1.036	4.284	3.804	6.37	— 3
0.250	1.199	4.705	3.037	1.09	— 3

\* For  $T = 1900^\circ\text{K}$ .TABLE 5.—DIFFUSION AND EVAPORATION OF ELEMENTS  
CONTAINED IN W AS OXIDES (8)

$D$  cm<sup>2</sup>/sec = diffusivity;  $E$  atoms/(cm<sup>2</sup> sec) = rate of normal evaporation of the element from the surface of the W;  $H_d$  g-cal = heat of diffusion = quantity of heat required to produce the diffusion of 1 g-atom of the diffusing material through the metal (here W) in which it is contained.  $D = d \times 10^{-11}$ ;  $E = e \times 10^9$ ;  $H_d = h \times 10^3$ ;  $T = 2000^\circ\text{K}$ .



TABLE 5.—(Continued)

	d	e	h
Ce.....	95	1450	83
Th*.....	5.9	1.53	94
U.....	1.3	>Th	100
Yt.....	1820		62
Zr.....	324	68	78

\* Langmuir<sup>(21)</sup> finds for Th,  $\log_{10} D = 0.044 - 20540/T$ ;  $\log_{10} E = 31.434 - 44500/T$ .

TABLE 6.—THERMIONIC WORK FUNCTION ( $\phi$ ): CALORIMETRIC DETERMINATION

$\phi_c$  = value by calorimeter,  $\phi_b$  = value computed from  $b_2$  (from  $b_1$ , in case of (40)); same material for each. Unit of  $\phi$  = 1 volt =  $1.591 \times 10^{-12}$  erg per electron.

Elementary substances				Oxides on Pt					
Material	$\phi_c$	$\phi_b$	Lit.	Oxides			$\phi_c$	$\phi_b$	Lit.
C.....	4.55		(24)	Ba	Ca	Sr			
Mo*.....	4.59		(24)	50	25	25	{ 2.39 2.34 2.54 2.59 }	{ 2.34 2.59 2.02 2.16 }	(40)
Os.....	4.7		(2)						
Pt.....	5.9		(38)	50	0	50	{ 1.97 2.02 2.28 2.16 }	{ 2.02 2.16 1.65 1.65 }	(40)
Ta.....	4.51		(24)						
W.....	4.52	4.52	(4)	(?)	0	(?)	1.61	1.65	(5)
	4.48		(24)	0	100	0	3.22	3.28	(40)

\* Effect of gas, Mo at 200°C (36): A,  $\phi_c = 4.76$ ; H<sub>2</sub> + A,  $\phi_c = 4.04$  to 4.35; N<sub>2</sub>,  $\phi_c = 4.77$  to 5.01.

Electron emission data for fused gold, silver and copper above and below the melting point have been measured by Goetz (12). Values of A and b vary with the temperature. For a comprehensive discussion of theory and data, see W. Schottky and H. Rothe, *Physik der Glühelktroden, Handbuch der Experimentalphysik*, 13 II, Leipzig, 1928.

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## CONTACT POTENTIALS

SAUL DUSHMAN

## CONTENTS

Data from photoelectric effect (illustrative).

Data from thermal emission of electrons (illustrative).

Contact potentials.

Metals with brass: condenser method.

Metals with platinum.

Miscellaneous pairs of conductors: condenser method.

Dielectrics in contact with Hg and amalgams.

## MATIÈRES

Données déduites de l'effet photoélectrique (explicatif).

Données déduites de l'émission thermique des électrons (explicatif).

Potentiels de contact.

Métaux avec laiton: méthode du condensateur.

Métaux avec platine.

Diverses paires de conducteurs: méthode du condensateur.

Diélectriques en contact avec Hg et les amalgames.

## INHALTSVERZEICHNIS

Daten aus dem photoelektrischen Effekt (erläuternd).

Daten aus der thermischen Elektronenemission (erläuternd).

Kontaktpotentiale.

Metalle mit Messing: Kondensatormethode.

Metalle mit Platin.

Verschiedene Konduktorpaaere: Kondensatormethode.

Dielektrika in Kontakt mit Quecksilber und Amalgamen.

## INDICE

PAGE

Valori derivati dall'effetto fotoelettrico (esemplificazione)..... 57

Valori derivati dalla emissione termica di elettroni (esemplificazione).... 57

Potenziali di contatto.

Metalli con ottone: metodo del condensatore. 57.

Metalli con platino..... 57

Coppie varie di conduttori: metodo del condensatore..... 57

Dielettrici in contatto con Hg e amalgame..... 57

If the heat absorbed when one unit of electricity passes (1) from the free surface of conductor A to the free surface of conductor B, in contact with A, is  $H'_{AB}$ ; (2) across the junction from A to B =  $P_{AB}$ ; (3) from surface of A [B] to infinity =  $P_{AS}$  [ $P_{BS}$ ]; then  $P'_{AB} = P_{AB} - P_{BS} + P_{AS}$ . Let  $K_{AB} = V_A - V_B$  = contact potential of A with reference to B;  $V_A$ ,  $V_B$  are the simultaneous potentials of A, B when in contact (2, 5). From thermodynamics, it follows that  $dK_{AB}/dT = -P'_{AB}/T$ ; for Fe and Ni this amounts to 0.000032 volt/degree at 50°C, while the experimental value for the range 20 to 60°C is 0.0016 volt/degree (5). The discrepancy is ascribed to the formation of a thin surface layer of oxide.

The value of  $K_{AB}$  may be deduced from data pertaining to the thermo- and photo-emission of electrons. If  $I$  = current per unit area carried by the thermoelectrons,  $K_{AB} = \frac{k_0 T}{e} \log_e \frac{I_A}{I_B}$ , and if  $I = AT^2 e^{-\phi_0/k_0 T}$  (cf. p. 53),  $K_{AB} = \phi_B - \phi_A + \frac{k_0 T}{e} \log_e \frac{A_A}{A_B}$ .

If A is a universal constant (18),  $K_{AB} = \phi_B - \phi_A$ .

If  $\nu_0$  = threshold frequency for emission of photoelectrons,  $V_{rAs}$  = retarding voltage = potential to which A must be raised above the anode in order to prevent the emission of photoelectrons under action of radiation of frequency  $\nu$ , and  $K_{As}$  = contact potential of A with reference to anode, then (12, 15)  $(V_{rAs} + K_{As})e = h(\nu - \nu_{0A})$  and  $K_{AB} = V_{rBa} - V_{rAs} + (\nu_{0B} - \nu_{0A})h/e = V_{rBa} - V_{rAs} + (\phi_B - \phi_A)$ ; this equation is confirmed by experiments (9, 15). Millikan (15) cal.  $(V_{rBa} - V_{rAs})$  the "spurious" and  $(\nu_{0B} - \nu_{0A})h/e$  the "intrinsic" contact potential. For clean metals  $V_{rBa} = V_{rAs}$ ; for others the equality may fail (15). Comparing this expression for  $K_{AB}$  with that derived from thermoelectronic data, it is obvious that  $V_{rBa} - V_{rAs} = \frac{k_0 T}{e} \log_e \left( \frac{A_A}{A_B} \right)$ , if  $\phi$  denotes the same quantity in each case (18).



Many of the following data are not very reliable, but those obtained under similar conditions probably indicate the correct order of the conductors in a Volta series.

TABLE 1.—VALUES OF THE WORK FUNCTION ( $\phi$ ) AS DERIVED FROM THE WAVE-LENGTH LIMIT ( $\lambda_0$ ) OF THE PHOTOELECTRIC EFFECT: ILLUSTRATIVE DATA

Values for other substances may be derived from the photoelectric data on pages 67–69.

$\phi = \frac{hc}{\lambda_0}$ ;  $K_{AB} = V_{rB} - V_{rA} + \phi_B - \phi_A = \frac{k_0 T}{e} \log_e \frac{A_A}{A_B} + \phi_B - \phi_A$  where  $A_A$  and  $A_B$  have the values derived from thermal electron emission data, p. 53. For clean surfaces,  $K_{AB} = \phi_B - \phi_A$ .  $\phi/v_0 = 4.117 \times 10^{-18}$  (volt sec);  $\phi\lambda_0 = 12\,344$  (volt Ångström). Unit of  $\lambda_0 = 1 \text{ Å} = 10^{-8} \text{ cm} = 10^{-4} \mu$ ; of  $\phi = 1 \text{ volt} = 10^8 \text{ cgsm unit} = 3.33 \times 10^{-3} \text{ cgse unit}$ .

Conductor	$\lambda_0$	Lit.	$\phi$	Conductor	$\lambda_0$	Lit.	$\phi$
Li.....	5263	(14)	2.35	Pt.....	2570	(11)	4.80
Na.....	5770	(6)	2.14		2910	(19)	4.24
	to		to		2960	(21)	4.17
	5830		2.12	Ta.....	3283	(21)	3.76
	6800	(13)	1.82	W.....	2200	(7)	5.61
	4860	(21)	2.54		3062	(21)	4.03
				BaO, SrO*	2860†	(11)	4.31
					3800†	(11)	3.24

\* On Pt. † At 20°C. ‡ At 420°C.

TABLE 2.—CONTACT POTENTIAL DEDUCED FROM THERMAL EMISSION OF ELECTRONS

Data for other pairs of conductors may be computed from the data on pages 55–56, by the relation  $K_{AB} = \phi_B - \phi_A + \frac{k_0 T}{e} \log_e \frac{A_A}{A_B}$ . All data from (22) refer to metals in vacuum.  $K_{AB} = V_A - V_B$ . Unit of  $K_{AB} = 1 \text{ volt}$ .

A	B	$K_{AB}$	Lit.
Al.....	C	+0.87	(22)
C.....	C-black*	-0.24	(22)
C.....	Fe	-0.02	(22)
C-black*	W	+0.36	(22)
Fe.....	W	0.00	(22)
W.....	Zn	-0.51	(22)
W <sub>hot</sub> .....	Cu <sub>cold</sub>	†	(20)
Pt <sub>hot</sub> .....	Pt <sub>cold</sub>	+0.16†	(20)
Th W <sub>hot</sub> §.....	W <sub>cold</sub>	+0.71	(20)

\* Lampblack.

† Presence of H<sub>2</sub> makes W more positive; Hg vapor has no effect.

‡ In H<sub>2</sub>, pressure = 0.112 mm of Hg; temp. of Pt<sub>hot</sub> = 1460°K.

§ Th W = Thoriated W.

TABLE 3.—CONTACT POTENTIAL OF METALS WITH BRASS: CONDENSER METHOD; ROOM TEMPERATURE

Values tabulated are the differences  $V_{\text{metal}} - V_{\text{brass}}$  columns (1), (2), (3); metal in vacuum; (1) surface freshly scraped; (2) four days after scraping; (3) before scraping. Column (4) metal in air at atmospheric pressure; (5) in air at pressure of 0.0001 mm; (6) highest value obtained after heating to high temperature in vacuum; (7) in air at atmospheric pressure; (8) in air at room temperature and atmospheric pressure. Unit of potential = 1 volt =  $10^8 \text{ cgsm unit} = 3.33 \times 10^{-3} \text{ cgse unit}$ .

Metal	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ag.....	+0.05	0	-0.097	+0.19*	+0.20*	+0.90*	-0.35	-0.286
Al.....	+1.04	+0.874	+0.293	-0.23	-0.22	+0.02	-0.33	+0.670
Au.....							+0.07	-0.269
Bi.....							-0.15	-0.154
Cu.....	+0.10	-0.110	-0.106	-0.04*	-0.04*	+0.44*	0.00†	+0.040
Fe.....	+0.24	+0.192	+0.053					

TABLE 3.—(Continued)

Metal	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mg.....	+1.47	+0.713	+0.825					
Ni.....				+0.16	+0.18	+0.47	+0.09	
Pb.....							+0.41	+0.396
Pt.....				-0.30*	-0.28*	-0.23*	-0.32	-0.354
Sb.....							+0.15	
Sn.....	+0.32	+0.317	+0.216					+0.318
Zn.....	+0.64	+0.496	+0.193	-0.596‡			+0.43*	+0.608
Brass.....	+0.26	+0.228	-0.123					
Lit.....	(8)	(8)	(8)	(26)	(26)	(26)	(16)	(1)

\* Mean of observations on 2 different specimens. † Same for steel.

‡ One hr after polishing; 1 week after polishing found -0.543; both surfaces polished (23).

TABLE 4.—CONTACT POTENTIAL ( $K$ ) OF METALS WITH PLATINUM (19)

$K = V_{\text{metal}} - V_{\text{Pt}}$ ; unit = 1 volt =  $10^8 \text{ cgsm unit} = 3.33 \times 10^{-3} \text{ cgse unit}$

Metal.....	Al	Bi	Cu	Mg	Na	Sn	Zn
$K$ .....	1.20	0.35	0.13	1.05	2.40	0.62	0.90

TABLE 5.—CONTACT POTENTIALS OF MISCELLANEOUS PAIRS OF CONDUCTORS: CONDENSER METHOD; ROOM TEMPERATURE  
For metals with brass, see Table 3;  $K_{AB} = V_A - V_B$

A	B	$K_{AB}$	Lit.	A	B	$K_{AB}$	Lit.
Al*.....	Fe	+0.87	(4)	Pt.....	Zn		(10)
Al*.....	Zn	+0.29	(4)	K.....	Pt	+2.8	(25)
Fe*.....	Zn	-0.60	(4)	C + NH <sub>3</sub> ¶.	Cu	+0.079	(24)
CuO*.....	Li	-1.52†	(14)	C + H <sub>2</sub> ¶.	Cu	+0.096	(24)
		-1.11‡	(14)	C + N <sub>2</sub> ¶.	Cu	+0.129	(24)
CuO*.....	Na	-2.52	(14)	C + CO <sub>2</sub> ¶.	Cu	+0.130	(24)
Cd§.....	Hg	-0.22	(17)	C + NO¶.	Cu	+0.136	(24)
Hg§.....	Sb	-0.26	(17)	C + O <sub>2</sub> ¶.	Cu	+0.142	(24)
Hg§.....	Zn	+0.17	(17)	C + O <sub>3</sub> ¶.	Cu	+0.155	(24)
Bi  .....	Pt		(16)				

\* In vacuum. † Fresh surface. ‡ Oil surface.

§ Initial value in dry air, pressure = 0.66 mm Hg.  $K_{AB}$  varies with the time. Author also gives data for moist air, H<sub>2</sub> and CO<sub>2</sub>.

¶ Distilled in vacuum; initially  $K_{AB}$  is low, traces of air cause the Bi and Zn to become more positive; after passing a maximum, an equilibrium value is approached. ¶ Coconut charcoal saturated with the gas indicated.

TABLE 6.—SIGNS OF CHARGES ACQUIRED BY DIELECTRICS IN CONTACT WITH Hg AND WITH AMALGAMS (3)  
Surfaces in high vacuum

Dielectric	Hg	Ag-Hg	Na-Hg	Zn-Hg
Amber.....	-	-	+	+
Diamond, C.....	-	-	-	-
Ebonite.....	-	-	+	+
K-glass.....	-	-	+	-
Na-glass.....	-	-	+	+
Sealing wax.....	-	-	+	+
Quartz, SiO <sub>2</sub> .....	-	-	+	+

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(10) Hughes, 3, 28: 337; 14. (11) Koppius, 2, 18: 443; 21. (12) Langmuir, 78, 29: 125; 16. (13) Millikan, 2, 4: 73; 14. (14) Millikan, 2, 7: 18; 16. (15) Millikan, 2, 18: 236; 21. (16) Pellat, 6, 24: 5; 81. (17) Perucca, 34, 178: 551; 21. (18) Richardson, *Electron theory of matter*. London, Cambridge Univ. Press, 1916. (19) Richardson and Compton, 3, 24: 575; 12.  
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## CURRENT FLOW IN VACUUM TUBES WITH HOT CATHODES

ALBERT W. HULL

## CONTENTS

	PAGE
Symbols.....	58
Ideal diodes.....	58
Characteristics of typical commercial diodes.....	59
Characteristics of typical commercial triodes.....	59

In what follows it is assumed that the emission of electrons (or ions) from the cathode (see p. 53) is so ample that the current through the tube is not limited by it.

**Diodes.**—If the carriers are emitted with velocity = 0, then in all cases  $i = KGV_a^{1/2}$ , where the value of  $KG$  depends only upon the construction of the tube and upon the system of units employed.  $K$  depends upon  $e/m$  and  $G$  upon certain ratios determined by the geometrical configuration of the conductors in the tube;  $G$  is dimensionless. Except in certain ideal cases,  $KG$  is treated as a single quantity and is denoted by  $k$  (see Table 3).

**Triodes (10, 22).**—If the carriers are emitted with velocity = 0, and if there is no magnetic field,  $i (= i_p + i_g) = k(E_p + \mu E_g)^{1/2}$ , approximately, see (20);  $k$  has the same value as for the corresponding diode;  $\mu$  depends solely upon the geometrical configuration of the conductors in the tube (1, 4, 17, 20), but by varying the size of the grid mesh, it can be given any desired value. The mutual conductance ( $g_m$ ) is a function of  $i_p$ , but for a given value of  $i_p$ , it is nearly independent of size of grid mesh. It is roughly proportional to length of cathode filament and inversely proportional to distance between grid and filament (see Table 4).

**Tubes with Four Electrodes.**—Space-charge grid tubes have the second grid next to the filament; the presence of this grid multiplies  $g_m$  by approximately 4, but the other constants remain the same as for the corresponding triode (21). Screen-grid tubes have the second grid between grid and plate. If screening is perfect,  $i_p$  is a function of  $E_p$  only, and the value of  $g_m$  is only about  $3/4$  as great as in the corresponding triode (7, 21).

## SYMBOLS

$A$	Area of one side of a plate electrode
$c$	Velocity of light in vacuo.
cgse	Cgs electrostatic system of units.
cgsu	Cgs electromagnetic system of units.
csva	Cm-sec-volt-ampere system of units, absolute volt and ampere.*
csVA	Cm-sec-volt-ampere system of units, international volt and ampere.*
$E_p, E_g$	Potential of plate, grid, above that of cathode.
$e$	Negative electronic charge.
$e$	Negative charge of the carrier of electricity (electron or ion).
$G$	Geometrical factor of $k$ .
$g_m$	Mutual conductance of plate and grid, $g_m = -\partial i_p / \partial E_g$ , $E_p$ being constant.
$H$	Strength of magnetic field externally applied parallel to axis of cylindrical electrodes.
$I$	Current flowing through the inner cylindrical electrode parallel to its axis.
$i, i_p, i_g$	Current to cathode: Total, from plate, from grid; $i = i_p + i_g$ .
$K$	Physical factor of $k$ .

\* In csva system, unit of mass is  $10^7$  g; required by relation  $eV = \frac{1}{2}mv^2$ . In csVA system, unit of mass is  $\frac{10^7}{1.00032}$  g.

$k_0$	Boltzmann gas constant.
$k$	Space charge constant characteristic of the tube; $k = KG$ .
$l$	Length of cylindrical electrode.
$M$	Molecular weight of the carrier ions.
$m$	Mass of the carrier of electricity (electron or ion).
$m_0$	Mass of negative electron at low velocity.
$r_a, r_c$	Radius of anode, cathode.
$r_o, r_i$	Radius of outer, inner, of two coaxial cylinders, or of two concentric spheres.
$R_p$	Plate resistance; $R_p = 1/(\partial i_p / \partial E_p)$ , $E_g$ being constant.
$T$	Absolute temperature of the carriers of electricity, °K. For thermionic carriers, $T$ = temperature of cathode (3); for electrons from low pressure arcs, $T$ is nearly independent of current density, but depends upon the nature and pressure of the gas, and ranges from 10 000 to 50 000°K (16).
$V$	Excess of potential above that of cathode.
$V_m$	Minimum value of $V$ in space between anode and cathode.
$V_a$	Potential of anode above that of cathode.
$v$	Velocity of carrier.
$v_i$	Initial velocity of carrier.
$x$	Distance from cathode in direction of anode.
$x_m$	Value of $x$ corresponding to $V_m$ .
$x_a$	Distance between anode and cathode.
$\alpha^2, \beta^2$	Functions of $r_o/r_i$ .
$\epsilon$	Dielectric constant of a vacuum. In cgse system, $\epsilon = 1$ ; in cgsu, $\epsilon = c^{-2}$ ; in csva, $\epsilon = (10)^2 c^{-2}$ ; in csVA, $\epsilon = 1.00052(10)^2 c^{-2}$ .
$\mu$	Amplification factor; $\mu = -dE_p/dE_g$ , $i_p$ being constant.

TABLE 1.—IDEAL DIODES

$K_e$  = value of  $K$  if carriers are electrons;  $K = K_e \sqrt{em_0/em} = K_e \sqrt{e/(1847Me)}$ . || Plates, Coax. Cyl., Con. Sph. = parallel plates, coaxial cylinders, concentric spheres. General formulae are valid for any consistent system of units; a numerical value is valid only for the indicated system of units.

Electrodes	$G$	Formula, $K$	cgse	csVA	Lit.
			$k_e$	$n$	
Magnetic field = 0, $v_i = 0$ ; $i = KGV_a^{1/2}$ ; $K_e = k_e \times 10^4$					
Plates....	$\frac{A}{x_a^2}$	$\frac{\sqrt{2}}{9\pi} \epsilon \sqrt{\frac{e}{m}}$	3.643	+7 2.341	-6 (2, 8, 11)
Coax. cyl....	$\frac{l^2}{r_a \beta^2}$	$\frac{2\sqrt{2}}{9} \epsilon \sqrt{\frac{e}{m}}$	22.89	+7 14.71	-6 (13, 15)
Con. sph....	$\frac{l^2}{a^2}$	$\frac{4\sqrt{2}}{9} \epsilon \sqrt{\frac{e}{m}}$	45.78	+7 29.42	-6 (14)
Magnetic field = 0, $v_i$ has a Maxwellian distribution (12)					
Plates....		$i = GK(V_a - V_m)^{1/2} \left(1 + C \sqrt{\frac{T}{V_a}}\right)$ , where $K$ has same value as for $v_i = 0$ , $G = A/(x_a - x_m)^2$ , and $C = 2.66 \sqrt{\frac{k_0}{e}}$ . If $e = e$ , then $C = 0.001426$ cgse = 0.0247 csVA.			
Coax. cyl....		Magnetic field = 0, $v_i = 0$ $i = GKV_a^{1/2}$ if $V_a > V'$ ; $i = 0$ , if $V_a < V'$ . $G$ and $K$ have same values as for field = 0; $V' = \frac{e}{m} \times \left[\frac{H^2 r_o^2}{8} + 2I^2 \left(\log \frac{r_o}{r_i}\right)^2\right]$ . In the csVA system, $V' = 0.0221 H^2 r_o^2 + 0.0188 I^2 \left(\log_{10} \frac{r_o}{r_i}\right)^2$ , if carriers are negative electrons.			

\* For values of  $\alpha^2$  and  $\beta^2$ , see Table 2.



TABLE 2.—VALUES OF COEFFICIENTS  $\alpha^2$  AND  $\beta^2$ 

For coaxial cylinders,  $G = l/(r_o\beta^2)$ ; for concentric spheres,  $G = 1/\alpha^2$  (see Table 1)

Cathode, $r_o/r_i$	Inside $\alpha^2$ (14)	Outside $\beta^2$ (13)	Inside	Outside
1.1	0.0086	0.0096	0.0001	0.01
1.5	0.1302	0.2118	0.1193	0.228
2.0	0.326	0.750	0.2793	0.845
3.0	0.669	2.512	0.5170	2.98
4.0	0.934	4.968	0.6671	6.06
5.0	1.141	7.98	0.7666	9.89
10	1.777	29.2	0.9782	37.0
20	2.378	93.2	1.0715	115.6
50	3.120	395	1.0936	450.2
100	3.652	1 144	1.0782	1 175
200	4.166	3 270	1.0562	2 946
500	4.829	13 015	1.0307	9 502
1 000	5.328		1.0171	
$\infty$			1.0000	

TABLE 3.—CHARACTERISTICS OF TYPICAL COMMERCIAL DIODES (6)

In all cases  $i = kV_a^{1.5}$  (9). The tubes are so constructed that, for the size of anode used,  $k$  is as great as is now (Jan., 1927) considered practical. The values are for American tubes, but do not differ appreciably from those for similar tubes constructed elsewhere.  $i_f$ ,  $E_f$  = filament current, voltage;  $E_m$  = maximum effective A.C. input voltage;  $i_m$  = maximum rectified tube current;  $P_n$  = nominal power rating; ThW, PW = thoriated tungsten, pure tungsten, filament. Unit of  $i_f$  and  $i_m$  = 1 ampere; of  $E_f$  and  $E_m$  = 1 volt; of  $P_n$  = 1 kilowatt; of  $k$  = 0.0001 ampere/volt<sup>1.5</sup>.

Type	$i_f$	$E_f$	$E_m$	$i_m$	$P_n$	$k$
ThW.....	1.25	7.5	550	0.065	0.0075	1.2
ThW.....	3.25	10	1 500	0.20	0.050	1.7
ThW.....	3.85	11	2 500	0.25	0.250	1.1
PW.....	14.7	11	16 000	0.166	1.00	0.5
PW.....	24.5	22	17 500	0.833	5.00	1.0
PW.....	52	22	18 000	3.0	20.00	1.1
PW.....	10	10	20 000	0.10		0.10
PW.....	10	10	85 000	0.10		0.11
PW.....	32	9	75 000	0.25		0.25
PW.....	10	10	150 000	0.100		0.11
PW.....	32	12.5	150 000	0.25		0.11

TABLE 4.—CHARACTERISTICS OF TYPICAL COMMERCIAL TRIODES

The following data for American tubes differ but little from those for corresponding tubes manufactured elsewhere. Ox, ThW; PW = oxide coated, thoriated tungsten, pure tungsten filaments;  $i_f$  = filament current,  $E_f$  filament voltage;  $E_p$  = normal plate voltage,  $L$ ,  $D$  = overall length, diameter, of tube;  $P_a$  = safe continuous energy dissipation at anode;  $P_o$  = rated power output;  $E_g$ ,  $i_p$  = grid voltage, plate current, for normal operation as amplifier. Unit of  $i_f$  = 1 ampere; of  $i_p$  = 0.001 ampere; of  $E_f$ ,  $E_p$ ,  $E_g$  = 1 volt; of  $L$ ,  $D$  = 1 cm; of  $P_a$ ,  $P_o$  = 1 kilowatt; of  $g_m$  = 0.001 mho = 0.001 ohm<sup>-1</sup>.  $\mu$  is dimensionless.

Standard American Triodes (18, 19)

Type	$i_f$	$E_f$	$L$	$D$	R.C.A. name	$E_p$	$E_g$	$i_p$	$g_m$	$\mu$	$P_a$	$P_o$
Ox.....	0.25	1.1	10	3.0	WD11	90	— 4.5	2.5	0.425	6.6		
Ox.....	0.25	5.0	12	4.6	UX112-A	135	— 9	10.0	1.70	8.0		
ThW.....	0.06	3.0	10	3.0	UX199	90	— 4.5	2.5	0.425	6.6		
ThW.....	0.125	3.0	10	3.0	UX120	135	— 22.5	6.5	0.500	3.3		
ThW.....	0.50	5.0	12	4.6	UX171	180	— 40.5	20	1.500	3.0		
ThW.....						135	— 27	17	1.360	3.0		
ThW.....	0.25	5.0	12	4.6	UX201-A	135	— 9	3.0	0.800	8.0		
ThW.....						90	— 4.5	2.5	0.725	8.0		
ThW.....	0.25	5.0	12	4.6	UX240	135	— 1.5	0.20	0.200	30.0		
ThW.....	1.25	7.5	14	5.5	UX210	425	— 35	20	1.500	7.5		
ThW.....	3.25	10	20	5.4	UV203-A	1 000	0	120	5	25	0.10	0.075
ThW.....	3.85	11	36	10	UV204-A	2 000	0	300	5	25	0.25	0.25
ThW.....	15.5	11	45	15	UV851	2 000	— 60	350	15	20	0.750	1
PW.....	14.75	11	40	12.5	UV206	15 000	0	54	1.9	325	0.35	1
PW.....	24.5	22	57	15	UV208	15 000	0	195	3.2	240	1.0	5
PW.....	52	22	48	11	UV207	15 000	— 475	400	4.5	20	10	20

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Abraham, 125, 8: 42; 20. (2) Child, 2, 32: 492; 11. (3) Davison and Germer, 2, 20: 300; 22. (4) Eccles, 540, 1: 67; 19. (5) Hull, 2, 18: 31; 21. (6) Hull, 2, 25: 645; 25. (7) Hull and Williams, 2, 27: 432; 26. (8) Langmuir, 2, 2: 450; 13. (9) Langmuir, 63, 15: 348; 14. (10) Langmuir, 529, 3: 261; 15. (11) Langmuir, 120, 26: 731; 23. (12) Lang-

- muir, 2, 21: 419; 23. (13) Langmuir and Blodgett, 2, 22: 347; 23. (14) Langmuir and Blodgett, 2, 24: 49; 24. (15) Langmuir and Kingdon, 166, 57: 58; 23. (16) Langmuir and Mott-Smith, 120, 27: 449; 24. (17) von Laue, 8, 59: 465; 19. (18) Radio Corp. of America, Standard power radiotrons and rectrons; 1928. (19) Radio Corp. of America, Bull., Nov. 21, 1927. (20) Schottky, 125, 8: 1; 20. (21) Schottky, 125, 8: 299; 20. (22) Whittemore, 529, 14: Suppl.; 1926.



## EMISSION OF SECONDARY ELECTRONS

H. E. FARNSWORTH

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Symbols.	Symboles.	Symbole.	Simboli.....	60
Emission excited by impact of electrons.	Émission excitée par le choc des électrons.	Durch Elektronenstoss erregte Emission.	Emissione eccitata per mezzo di urto di elettroni.	
Retarding potential difference required to annul a velocity.	Différence de potentiel retardateur nécessaire pour annuler une vitesse.	Verzögernde Potential-Differenz, die erforderlich ist, um eine Geschwindigkeit aufzuheben.	Differenza di potenziale ritardatrice necessaria per annullare una velocità.....	61
Transmission and absorption.	Transmission et absorption.	Durchdringung und Absorption.	Trasmissione e assorbimento.....	61
Mass absorption coefficient and its variation with velocity.	Coefficient d'absorption de masse et sa variation avec la vitesse.	Massenabsorptionskoeffizient und seine Änderung mit der Geschwindigkeit.	Coefficiente di assorbimento di massa e sua variazione con la velocità.....	61
Mass absorption coefficients relative to air.	Coefficients d'absorption de masse relatifs à l'air.	Massenabsorptionskoeffizient bezogen auf Luft.	Coefficiente di assorbimento di massa per l'aria.....	61
Velocity of transmitted electrons.	Vélocité des électrons transmis.	Geschwindigkeit durchgedrungener Elektronen.	Velocità degli elettroni trasmessi.....	61
Decrease in number and in velocity of electrons during transmission through Al.	Diminution en nombre et en vitesse des électrons durant la transmission à travers Al.	Abnahme der Zahl und der Geschwindigkeit der Elektronen während des Durchganges durch Al.	Diminuzione di numero e di velocità degli elettroni durante la trasmissione attraverso Al.....	62
Variation of transmission with primary velocity	Variation de la transmission avec la vitesse primaire.	Änderung des Durchdringungsvermögens mit der Primärgeschwindigkeit.	Variazione della trasmissione in funzione della velocità primaria.....	62
Distribution of velocities: transmitted electrons.	Distribution des vitesses: électrons transmis.	Geschwindigkeitsverteilung: Durchgedrungene Elektronen.	Distribuzione delle velocità: elettroni trasmessi.....	62
Reflection of electrons: angular distribution, etc.	Réflexion des électrons: distribution angulaire, etc.	Reflexion der Elektronen: Winkelverteilung, u.s.w.	Riflessione di elettroni: distribuzione angolare, ecc.....	62
Emission from gases.	Émission à partir des gaz.	Emission aus Gasen.	Emissione dai gas.....	63
Emission from solids and liquids.	Émission à partir des solides et des liquides.	Emission aus festen und flüssigen Stoffen.	Emissione da solidi e da liquidi.....	63
Velocities of secondary electrons.	Vitesses des électrons secondaires.	Geschwindigkeit sekundärer Elektronen.	Velocità di elettroni secondari.....	64
Emission excited by impact of positive ions.	Émission excitée par le choc d'ions positifs.	Emission, hervorgerufen durch das Auftreffen positiver Ionen.	Emissione eccitata per urto di ioni positivi.....	64

The electrons and positive ions incident upon the substance under consideration are designated as "primary;" those leaving it, as "secondary." Generally the secondary electrons which result from impact of electrons are of two distinct classes: (a) those which have velocities of the same order as that of the primaries, and (b) those with much smaller velocities. The former are regarded as primary electrons which have been reflected [transmitted] by the substance; the latter, as electrons which originated in the substance.

## SYMBOLS

See also Vol. I, p. 16

$c$	Velocity of light.
$d$	Density.
$N$	Number of secondary electrons per primary electron or +ion.
$n$	Number of secondary electrons.

$V_r, V_p, V_z$	Retarding potential difference required to stop an electron which has the velocity $v, v_p, v_z$ .
$v, v_p, v_z$	Velocity of the electrons, of the primary electrons, of electrons at point $z$ .
$\Delta$	$v_p - v_z$ .
$\delta_\theta$	$[(N_\theta)_0 - (N_\theta)_\infty]/(N_\theta)_0$ .
$r$	Thickness.
$\theta$	Angle of incidence.
$\varphi$	Angle of emergence; like $\theta$ , $\varphi$ is measured from the normal.
Subscripts of special significance	
$f$	Fast electrons, velocity of same order as $v_p$ .
$s$	Slow electrons, velocity much less than $v_p$ .
$t$	Total electrons of all velocities.
$p$	Primary electrons.
1[2]	Electrons from 1st [2nd] surface of thin film; the 1st surface is the surface of incidence.



TABLE 1.—RETARDING POTENTIAL DIFFERENCE REQUIRED TO BRING AN ELECTRON TO REST: EINSTEIN'S RELATION

$v$  = initial velocity of the electron,  $V_e$  = potential difference required to reduce the velocity from  $v$  to 0. Einstein's relation is  $V_e = \frac{300mc^2}{e} \left\{ \frac{1}{\sqrt{1 - (v/c)^2}} - 1 \right\}$ ;  $300mc^2/e = 5.08 \times 10^5$  volt

$$V_e = A \times 10^5; V_e^2 = B \times 10^5$$

Unit of  $V_e$  = 1 volt.

$v/c$	$V_e$		$V_e^2$		$v/c$	$V_e$		$V_e^2$	
	A	n	B	n		A	n	B	n
0	0	0	0	0	0.30	2.45	4	6.00	8
0.005	6.4	0	4.0	1	0.35	3.43	4	1.18	9
0.006	9.1	0	8.4	1	0.40	4.63	4	2.14	9
0.010	2.54	1	6.4	2	0.45	6.08	4	3.70	9
0.015	5.7	1	3.24	3	0.50	7.86	4	6.18	9
0.020	1.02	2	1.03	4	0.55	1.00	5	1.01	10
0.025	1.58	2	2.51	4	0.60	1.27	5	1.61	10
0.03	2.29	2	5.24	4	0.65	1.60	5	2.56	10
0.04	4.07	2	1.66	5	0.70	2.03	5	4.12	10
0.05	6.36	2	4.04	5	0.75	2.60	5	6.76	10
0.07	1.25	3	1.56	6	0.80	3.39	5	1.15	11
0.10	2.56	3	6.55	6	0.85	4.56	5	2.08	11
0.15	5.82	3	3.39	7	0.90	6.57	5	4.32	11
0.20	1.05	4	1.10	8	0.95	1.12	6	1.46	12
0.25	1.66	4	2.77	8	0.99	3.09	6	9.55	12

## TRANSMISSION AND ABSORPTION OF PRIMARY ELECTRONS

During transmission, the beam of primary electrons is more or less scattered. If  $v_p$  is great and the film of substance is thin, the scattering may be negligible; it increases with the thickness ( $\tau$ ) and ultimately the electrons emerging from the second surface are distributed as  $\cos \varphi$  (66, 84). The thickness at which this first occurs increases with  $v_p$  and as the atomic weight decreases; if  $v_p/c = 0.48$  to  $0.59$  it is  $0.015$  cm for Al and  $0.0002$  cm for Au (24).

If primary electrons are incident at all angles, then, for an area which is far from the edges of the surface,  $N_{f_2} = e^{-\alpha\tau}$ , where  $\alpha$  is independent of  $\tau$  if  $\tau$  and  $v_p/c$  are small (61, 62); if  $\theta = 0$ ,  $\alpha$  is independent of  $\tau$  if  $v_p/c < 0.4$  (92);  $\alpha$  varies with  $v_p$  (see Table 2) and the velocity of the electrons decreases as they penetrate the substance (cf. Table 4), hence  $\alpha$  is independent of  $\tau$  only if  $\tau$  is so small that the resulting change in velocity is negligible. To obtain  $N_{f_2}$  for a thicker specimen, imagine the specimen to be built up of a series of very thin layers and compute the effect of each of these, taking into account the change of  $v_p$  from layer to layer. In this computation, the "most probable velocity" is used. If the initial beam is diffuse (electrons incident in all directions) or if the initial velocity is so low that the beam has become diffuse in a small part of the distance traversed, the velocity may be obtained from Tables 4 and 5. If the incidence is normal and not diffuse, the change in  $v_p$  from layer to layer may be obtained by solving the equation  $V_{vp}^2 - V_{v\tau}^2 = kd\tau$  (Table 4) for  $V_{v\tau}$  and obtaining the corresponding  $v$  from Table 1.

For  $v_p = 0.87c$ ,  $\alpha/d$  varies from ca. 5 to  $14 \text{ cm}^2/\text{g}$ , and for many substances =  $7 \text{ cm}^2/\text{g}$  (cf. Table 3). Other things being the same,  $\alpha/d$  is generally greater for a solid than for a liquid (1).

TABLE 2.—MASS ABSORPTION COEFFICIENT ( $\alpha/d$ ) AND ITS VARIATION WITH VELOCITY ( $v_p$ ) OF PRIMARY ELECTRONS (cf. TABLE 5)

For A, Br<sub>2</sub>, Cl<sub>2</sub>, H<sub>2</sub>, He, N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub>, CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>, NH<sub>3</sub> and SO<sub>2</sub>, at  $0^\circ$  and  $1 \text{ A}_\mu$  and for  $v_p = 0.35c$ ,  $\alpha = 0.0783MR \text{ cm}^{-1}$ , where  $M$  = molecular weight (14). For many metals,  $\alpha/d = a + bZ$  for the  $\beta$ -rays from RaD and RaE ( $v_p = 0.77c$ );  $Z$  = atomic num-

ber,  $a$  and  $b$  are constants (33, 59). For certain gases,  $\alpha$  passes through a maximum at the velocity corresponding to  $V_{vp} = V_{m\alpha}$  (see 2nd section of this table).

Lenard's data (61, 62) refer to diffuse, and Terrill's (92) to normal, incidence. If  $\alpha_d[\alpha_n]$  = value of  $\alpha$  for diffuse [for normal] incidence,  $\alpha_d = U\alpha_n$ ; at low velocities,  $U$  is practically unity; for values of  $U$  at higher velocities, see Lenard (61). Unit of  $\alpha/d = 1 \text{ cm}^2/\text{g}$ ; of  $V_{m\alpha} = 1 \text{ volt}$ ;  $\alpha/d = A \times 10^5$ .

(I) Air and Al\*

$v_p/c$	A	n	Lit.	$v_p/c$	A	n	Lit.
0.00	2.0	7	(61, 62)	0.35	1.4	3	(61, 62)
0.01	1.8	7	(61, 62)	0.36	7.4	2	(92)
0.02	1.3	7	(61, 62)	0.38	6.1	2	(92)
0.03	8.6	6	(61, 62)	0.40	4.9	2	(92)
0.04	5.8	6	(61, 62)	0.40	7.4	2	(61, 62)
0.06	2.5	6	(61, 62)	0.41	4.4	2	(92)
0.08	1.4	6	(61, 62)	0.45	4.0	2	(61, 62)
0.10	8	5	(61, 62)	0.50	2.2	2	(61, 62)
0.15	1.5	5	(61, 62)	0.55	1.3	2	(61, 62)
0.20	3.6	4	(61, 62)	0.60	8.3	1	(61, 62)
0.25	8.6	3	(61, 62)	0.65	4.9	1	(61, 62)
0.27	2.29	3	(92)	0.70	2.9	1	(61, 62)
0.28	1.99	3	(92)	0.75	1.9	1	(61, 62)
0.30	2.9	3	(61, 62)	0.80	1.3	1	(61, 62)
0.32	1.17	3	(92)	0.85	9	0	(61, 62)
0.34	9.2	2	(92)	0.90	6	0	(61, 62)
0.35	8.2	2	(92)				

## (II) Velocity of Maximum Absorption

Gas	$V_{m\alpha}$	Lit.	Gas	$V_{m\alpha}$	Lit.
Air	0	(61, 62)	He	4	(18)
A	12	(18)		3.6	(76)
	12.4	(78)	Hg†	0	(17, 71)
	13.2	(76)	Kr	11.3	(76)
CH <sub>4</sub>	7.5	(18)	N <sub>2</sub>	18	(18)
CO	18	(18)	Ne	22	(76)
Cd†	0	(17, 71)	Xe	6.4	(76)
H <sub>2</sub>	0	(18)	Zn†	0	(17)

\* For Al,  $\alpha/d = 7.0 \text{ cm}^2/\text{g}$  if  $v_p = 0.87c$ . † Vapor.

TABLE 3.—MASS ABSORPTION COEFFICIENT RELATIVE TO AIR  $R = (\alpha/d)/(\alpha/d)_{\text{air}}$ ; for  $(\alpha/d)_{\text{air}}$ , see Table 2

Substance	R	$v_p/c$	Lit.	Substance	R	$v_p/c$	Lit.
A	0.82	0.35	(14)	I <sub>2</sub>	2.36	0.92	(34)
Al	1.00	0.87	(61)	N <sub>2</sub>	1.03	0.35	(14)
Br <sub>2</sub>	1.56	0.50	(85)	O <sub>2</sub>	0.93	0.35	(14)
	1.86	0.92	(34)	Pt	1.94	0.87	(61)
Cl <sub>2</sub>	1.23	0.50	(85)	Sn	1.57	0.87	(61)
	1.33	0.92	(34)	CO <sub>2</sub>	1.00	0.35	(14)
Cu	1.40	0.87	(61)	CH <sub>4</sub>	1.44	0.35	(14)
H <sub>2</sub>	1.73	0.35	(14)	C <sub>2</sub> H <sub>4</sub>	1.22	0.35	(14)
He	0.72	0.35	(14)	NH <sub>3</sub>	1.33	0.35	(14)
I <sub>2</sub>	1.86	0.50	(85)	SO <sub>2</sub>	1.01	0.35	(14)

TABLE 4.—MOST PROBABLE\* VELOCITY OF TRANSMITTED ELECTRONS

If  $v_\tau$  = most probable\* velocity of the electrons transmitted by a sheet of thickness  $\tau$  when the incident electrons have the velocity  $v_p$  and are diffuse (incident at all angles) and  $\Delta\tau = v_p - v_\tau$ , then  $\Delta\tau/d$  varies with  $v_p$  (see Tables 2, 5) and with the transmitting substance. For normal incidence,  $V_{vp}^2 - V_{v\tau}^2 = kd\tau$ ; if  $v_p/c = 0.30$  to  $0.42$ ,  $k = 0.40 \times 10^{12} \text{ volt}^2 \text{ cm}^2 \text{ g}^{-1}$  for Al, Ag, Au, Be and Cu (91);  $k$  decreases from  $0.215 \times 10^{12}$  for Al to  $0.105 \times 10^{12}$  for Au in the order Al, Sn, Cu, Ag, air, Pt, Au (97). The



first <sup>(91)</sup> appears the more reliable. If  $v_p/c = 0.15$  to  $0.22$ ,  $k = 0.189 \times 10^{12}$  for Al and  $0.171 \times 10^{12}$  for Ni <sup>(53)</sup>.

From the value of  $\Delta_r$  for Al (Table 5) the value for the same thickness of another metal  $M$  is given by  $(\Delta_r/d)_M = F_M(\Delta_r/d)_{Al}$ ,  $d_{Al} = 2.7$  g/cm<sup>2</sup>. The following values of  $F_M$  <sup>(61)</sup> are approximate only:

Metal	$v/c$	$F_M$	Lit.
Ag	0.9	2.4	(13)
Al	See Table 5		
Au	0.1 to 0.3	0.5	(61, 97)
	0.9	3.2	(13)
Cd	0.9	2.4	(13)
Cu	0.6 to 0.7	0.9	(9)
	0.9	1.7	(13)
Fe	0.3 to 0.4	0.5	(61)
Ni	0.9	1.7	(13)
Pb	0.9	3.2	(13)
Pt	0.6 to 0.7	0.7	(9)
	0.9	3.2	(13)
Sn	0.3 to 0.4	0.5	(61)
	0.6 to 0.7	0.8	(9)
	0.9	2.4	(13)
Zn	0.9	1.7	(13)

\* If  $2(N_2)\delta v$  = number of the  $N_2$  electrons which have velocities lying between  $v - \delta v$  and  $v + \delta v$ , then the value of  $v$  for which  $(N_2)v$  is a maximum is called the "most probable velocity."

TABLE 5.—DECREASE IN NUMBER AND IN MOST PROBABLE\* VELOCITY ( $v$ ) OF ELECTRONS DURING TRANSMISSION THROUGH AL <sup>(61, 62)</sup>

Recent results <sup>(14)</sup> for  $v_p/c = 0.32$  and  $0.41$  agree with these older data, see also Table 6. Thickness of Al =  $A$  mm;  $N_{12} = i \times 10^n$ .

$A$	$f = 1$			$f = 0.1$		
	$v/c$	$i$	$n$	$v/c$	$i$	$n$
0	0.990	1.00	0	0.800	1.00	0
0.5	0.988	9.17	1	0.787	8.33	1
1.0	0.986	8.30	1	0.773	6.77	1
1.5	0.984	7.40	1	0.758	5.40	1
2.0	0.982	6.50	1	0.742	4.17	1
2.5	0.979	5.57	1	0.723	3.09	1
3.0	0.974	4.68	1	0.700	2.13	1
3.5	0.968	3.80	1	0.673	1.36	1
4.0	0.958	2.87	1	0.640	7.55	2
4.5	0.946	2.00	1	0.600	3.19	2
4.75	0.938	1.57	1	0.578	1.82	2
5.00	0.927	1.21	1	0.551	8.76	3
5.25	0.911	8.88	2	0.520	3.09	3
5.50	0.892	6.04	2	0.483	6.37	4
5.75	0.862	3.62	2	0.437	4.8	5
6.00	0.820	1.90	2			
6.25	0.760	8.03	3			
6.40	0.711	3.0	3			

\* See footnote of Table 4.

$A$	$f = 0.01$			$f = 0.001$		
	$v/c$	$i$	$n$	$v/c$	$i$	$n$
0	0.450	1.00	0	0.300	1.00	0
0.25		7.38	1		7.87	1
0.50	0.440	5.33	1		6.22	1
0.75		3.57	1		4.78	1
1.00	0.429	2.45	1	0.293	3.64	1
1.25		1.69	1		2.74	1
1.50	0.418	1.09	1		2.03	1
1.75		6.65	2		1.48	1

TABLE 5.—(Continued)

$A$	$f = 0.01$			$f = 0.001$		
	$v/c$	$i$	$n$	$v/c$	$i$	$n$
2.00	0.406	3.94	2	0.287	1.03	1
2.25		2.21	2		7.34	2
2.50	0.394	1.24	2		5.00	2
2.75		6.35	3		3.60	2
3.00	0.380	3.06	3	0.279	2.26	2
3.25	0.374	1.38	3		1.50	2
3.50	0.364	6.0	4		9.99	3
3.75	0.356	1.93	4		6.52	3
4.00	0.347	6.42	5	0.271	4.22	3
4.25	0.336	1.84	5		2.56	3
4.50	0.325	4.23	6	0.267	1.57	3
4.75	0.313	7.59	7		9.75	4
5.00	0.300	1.27	7	0.262	6.03	4
5.25					3.58	4
5.50				0.257	2.00	4
5.75					1.10	4
6.00				0.251	5.85	5
6.25					3.01	5
6.40				0.245		

TABLE 6.—VARIATION OF TRANSMISSION WITH PRIMARY VELOCITY: 0.0031 MM AL, NORMAL INCIDENCE <sup>(93)</sup>

$N_{f2}$  = number of high velocity electrons ( $V_e > 100$  volt), and  $N_{s2}$  = number of low velocity electrons ( $V_e < 100$  volt) emerging from second face of Al per unit primary electron striking first face. Total emergent per primary =  $N_{f2} + N_{s2} = N_1$ . Values of  $v_p/c$  are computed from  $V_{vp}$  (cf. Table 1). Unit of  $V_{vp} = 1$  kilovolt.

$V_{vp}$	$N_{f2}$	$N_{s2}$	$v_p/c$	$V_{vp}$	$N_{f2}$	$N_{s2}$	$v_p/c$
15.0	0.000	0.006	0.24	26.8	0.25	0.14	0.31
18.0	0.000	0.011	0.26	30.2	0.35	0.16	0.33
20.0	0.030	0.020	0.27	32.8	0.42	0.16	0.34
21.2	0.06	0.05	0.28	37.2	0.51	0.17	0.36
22.7	0.11	0.07	0.29	43.4	0.61	0.18	0.39
24.0	0.15	0.10	0.30				

TABLE 7.—DISTRIBUTION OF VELOCITIES AMONG ELECTRONS TRANSMITTED BY AL: NORMAL INCIDENCE <sup>(93)</sup>

$V_{vp} = 45.6$  kilovolt ( $v_p = 0.396c$ );  $\tau$  = thickness of Al;  $I$  is proportional to number of transmitted electrons having velocity defined by  $V_e$ . Unit of  $\tau = 1\mu = 10^{-4}$  cm; of  $V_e = 1$  kilovolt = 1000 volt.

$V_e$	25	29	31	33	35	37	39	41	42	43	44	45
$\tau$	$I$											
3.1					4.3	9.2	15.6	18.4	19.5	20.0	19.8	14.8
6.2			2.5	3.6	5.4	7.0	7.4	7.0	5.2	4.5	3.7	
9.3	0.8	1.8	2.0	2.3	2.1	1.8	1.4	1.0	0.8	0.6		

#### REFLECTION OF ELECTRONS: ANGULAR DISTRIBUTION, ETC.

For electron reflection by gases, see Baerwald <sup>(6)</sup>

At  $\beta$ -ray velocities ( $v/c = 0.50$  to  $0.80$ ),  $N_{f1}$  increases with atomic weight of reflector, but less rapidly than as the first power <sup>(65, 67, 80)</sup>; unless the thickness ( $\tau$ ) of the reflector exceeds a certain value ( $\tau_m$ ),  $N_{f1}$  increases and the average velocity of the reflected electrons decreases as  $\tau$  increases <sup>(46)</sup>. The greater the atomic weight of the reflector, the smaller is  $\tau_m$ . For  $v_p/c = 0.48$  to  $0.59$ ,  $(\tau_m)_{Al} = 0.04$  cm,  $(\tau_m)_{Pb} = 0.01$  cm <sup>(81)</sup>; for  $v_p/c = 0.55$  to  $0.65$ ,  $(\tau_m)_{Al} = 0.013$  cm <sup>(68)</sup>. For Al with  $\tau = 0.032$  cm and  $v_p/c = 0.77$ ,  $N_{f1} = N_{f2}$  <sup>(58)</sup>. The angular distribution of  $N_{f1}$  from thick reflectors is shown in Figs. 1, 2, 3 where  $n_0 =$



number of reflected electrons of velocity  $\geq v$  which lie within a small cone of solid angle  $\Delta\omega$  centered upon the radius vector,  $n_p$  = number of incident primary electrons,  $k$  = constant of proportionality;  $\Delta\omega$  and  $k$  are constant for all the curves in any one figure, but they vary from figure to figure. For each curve, the velocity of the incident electrons is indicated by the value of  $V_{vp}$  (unit = 1 volt) marked upon the curve;  $V_v = 0.90V_{vp}$  unless another value is indicated.

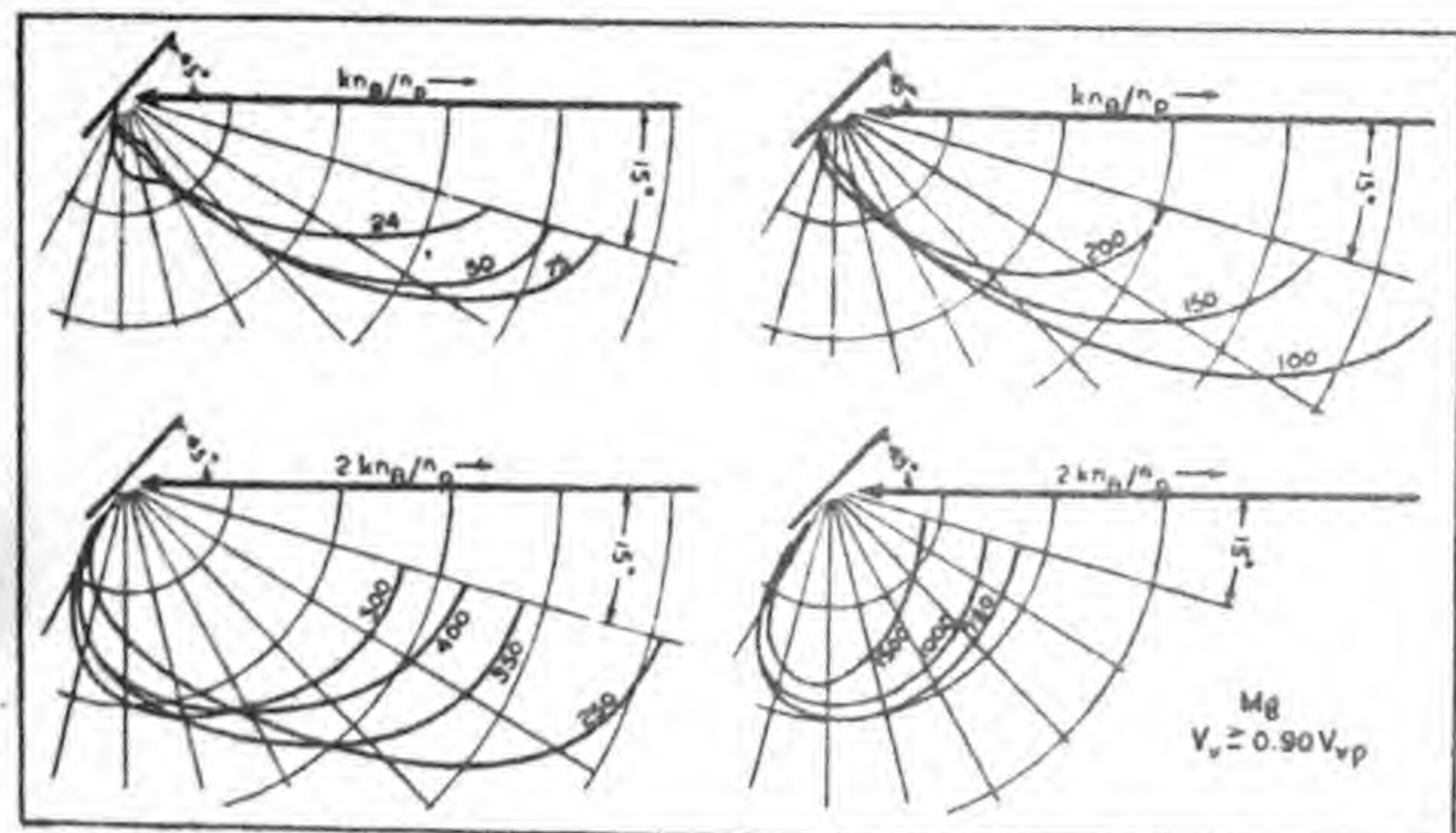


FIG. 1.—Angular distribution of secondary electrons from Mg (23, 24) (see text).

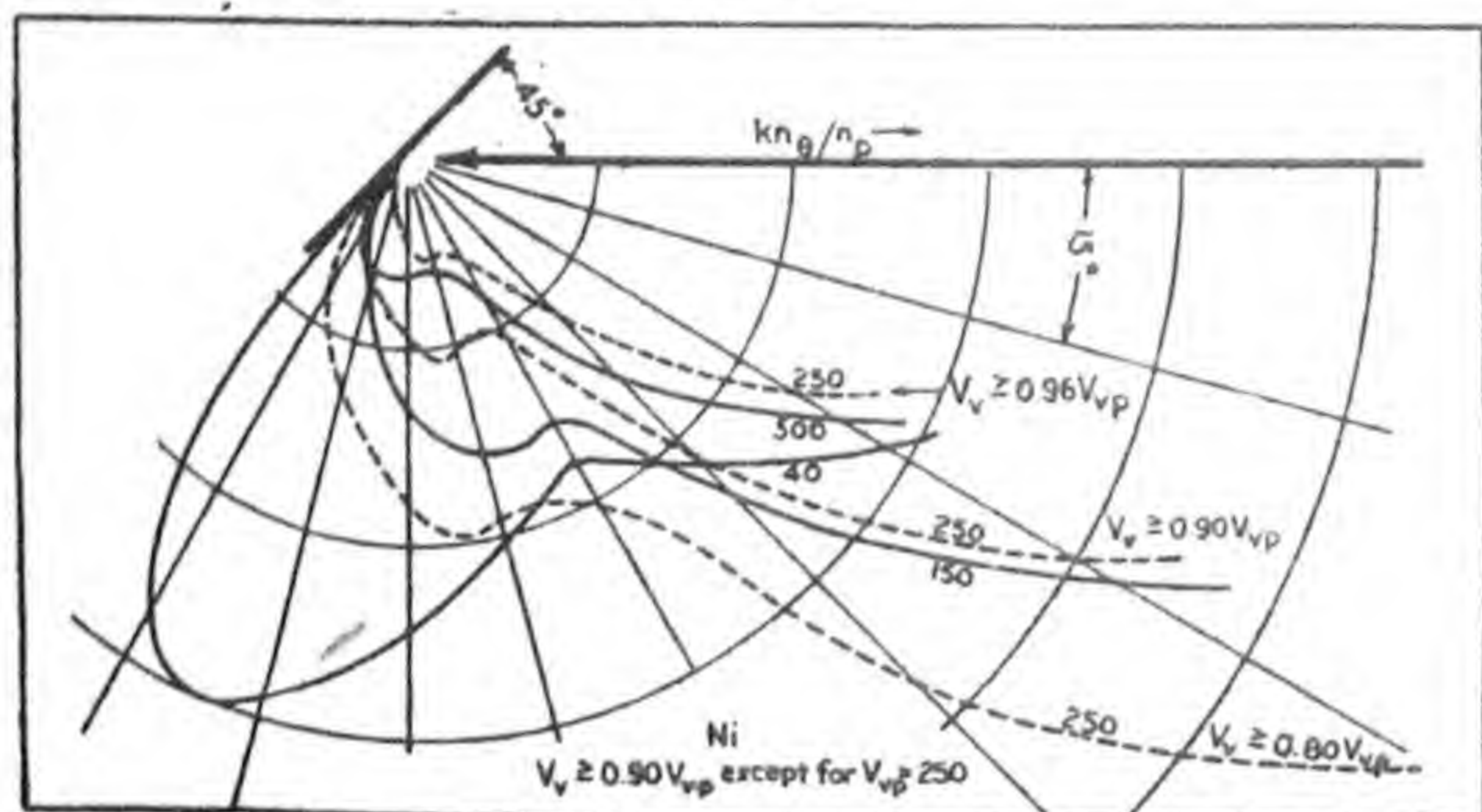


FIG. 2.—Angular distribution of secondary electrons from Ni: variation with the velocity (23, 24) (see text).

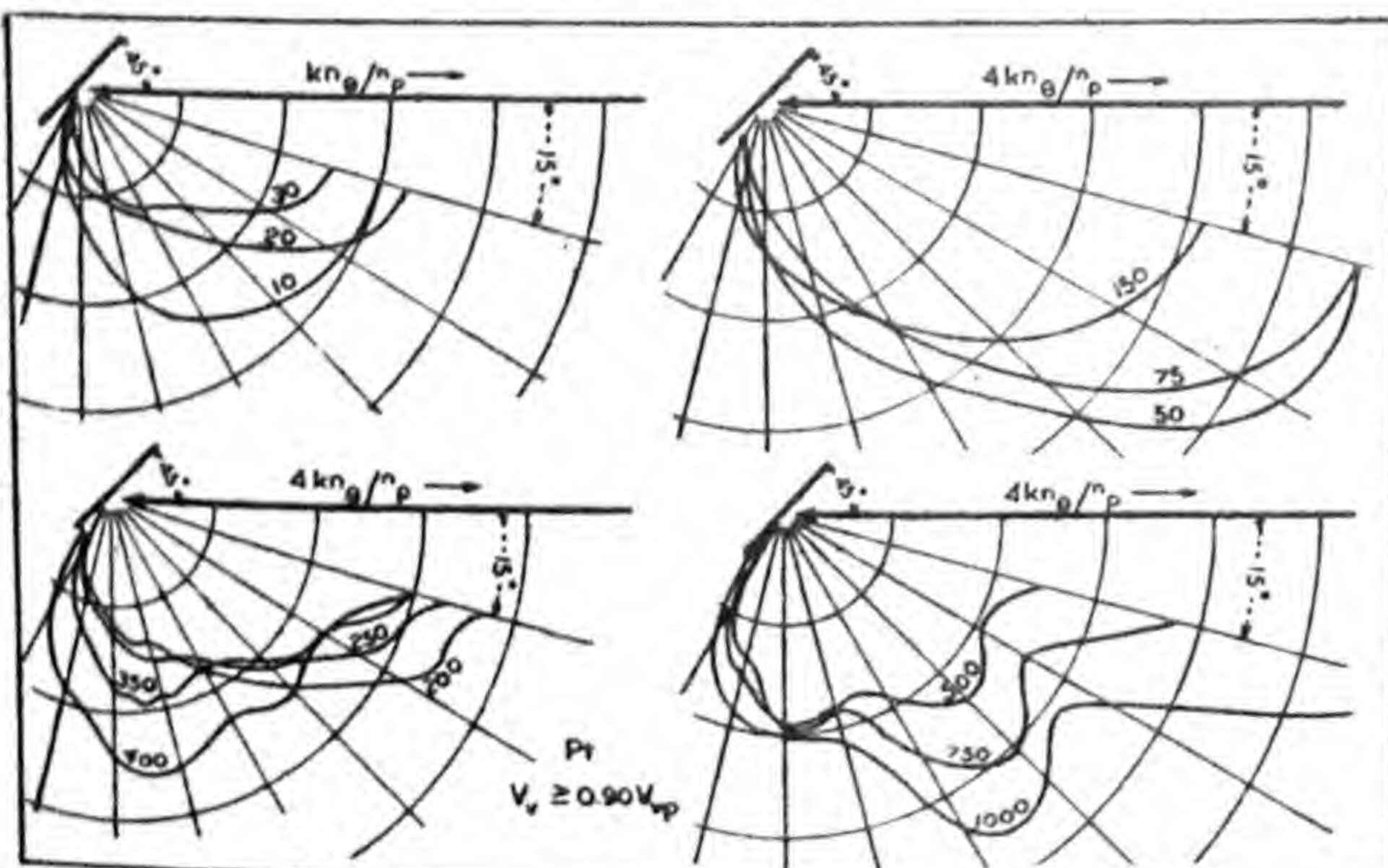


FIG. 3.—Angular distribution of secondary electrons from Pt (23, 24) (see text).

TABLE 8.—SECONDARY EMISSION OF ELECTRONS FROM GASES  
 $n_s = dN_s/dx$  = number of emitted slow electrons per primary and per unit of path;  $t_s = \int_0^\infty n_s dx$  = total number of slow electrons per primary at complete absorption.  $n_s$  and  $t_s$  vary with  $v_p$  and  $n_s$  passes through a maximum at  $(v_p)_m$  corresponding to  $(V_{vp})_m$  (see section C of table). If  $V_{vp} < 1500$  volt, the maxi-

imum value of  $(V_{vp})_m = 40$  volt and is independent of  $V_{vp}$  (94); if  $7000 \text{ volt} \leq V_{vp} \leq 15000 \text{ volt}$ ,  $(V_{vp})_m$  varies from 0 to 1000 volt, but for 90% of the slow electrons  $(V_{vp})_m < 40$  volt (49). In general,  $n_s$  is proportional to  $d$  and otherwise is independent of nature of the gas, but  $H_2$  is an exception. For it,  $n_s/d$  is greater than for other gases; see section B.

A. Air at 0°C and 1 atm. (61); see also Section C

$v_p/c$	$n_s$	$t_s$	$v_p/c$	$n_s$	$t_s$	$v_p/c$	$n_s$	$t_s$
0.006	0		0.25	580	53	0.70	95	1 990
0.024	7 700		0.30	400	100	0.75	80	2 570
0.03	7 500		0.35	308	160	0.80	69	3 310
0.04	5 000		0.40	250	247	0.85	59	4 200
0.05	3 200	(0.5)	0.45	210	385	0.90	50	5 400
0.07	2 300		0.50	180	580	0.95	45	8 600
0.10	1 700	2	0.55	152	830	0.99	41	26 800
0.15	1 200	7	0.60	131	1 150			
0.20	830	20	0.65	111	1 520			

B.  $H_2$ , Hydrogen;  $(n_s/d)_H = k(n_s/d)_{air}$

$v_p/c$	0.02	0.062	0.3	0.92
$k$	12	4	1.8	2

C. Optimum  $v$ . Unit of  $(V_{vp})_m = 1$  volt;  $N'$  = fraction of collisions which result in ionization (data of (23) appear to be the best).

Gas	$(V_{vp})_m$	$N'$	Lit.	Gas	$(V_{vp})_m$	$N'$	Lit.
Air	130		(69); cf. (16)	$N_2$ —	100		(51)
A	100		(51)	(Cont'd)	101	0.32	(47)
	80	0.35	(47)		175	0.451	(23)
	125	0.508	(23)	Ne	220		(51)
$H_2$	125		(69); cf. (16)		157	0.14	(47)
	74	0.21	(47)	CO	330	0.276	(23)
	145	0.315	(23)		125		(69); cf. (16)
He	140		(51)		120		(51)
	147	0.11	(47)	$CO_2$	140		(69); cf. (16)
	200	0.227	(23)		132		(69); cf. (16)
Hg	110	0.318	(23)	$CH_4$			(69); cf. (16)
$N_2$	150		(69); cf. (16)		80	0.28	(47)
				HCl	130	0.604	(23)

## EMISSION OF SECONDARY ELECTRONS FROM SOLIDS AND LIQUIDS

For angular distribution, see Figs. 1, 2, 3; for emission from thin films, see Tables 4, 5, 6 and p. 61

Heating in a vacuum increases  $N_i$  from Al and Mg and decreases it from other metals. For effect of occluded gases and of surface structure upon  $N_i$  from Cu, see (31). With many exceptions,  $N_i$  from liquids increases with the atomic weight; it increases with the coefficient of absorption of the primary electrons (1, 2). Slow secondary electrons do not appear if  $V_{vp} < (V_{vp})_s$ .

Metal.....	Ag	Au	Ni	Pd	Pt	W
$(V_{vp})_s$ .....	11	11	9	>9, <12	>9, <12	14 volt (31)

If  $v_p/c = 0.55$  to  $0.65$ ,  $\delta_{90^\circ} > 0$  and decreases as atomic weight increases; for Pb,  $\delta_{90^\circ} = 0.15$ ; for the esters,  $\delta_{90^\circ} = 2.17$  (2).

$v_p/c$	0.012	0.018	0.022	0.028	0.040	0.056	0.074
$100\delta_{90^\circ}$							
Al (11)	10.7	1.8	25.6	51.1	78.0	123.0	136.0
Pt (11)	10.8	4.4	33.7	76.5	100.2	127.0	116.0
$v_p/c$	0.090	0.124	0.198	0.327			
$100\delta_{90^\circ}$							
Al (11)	144.0	152.0	169.0	173.0			
Pt (11)	106.0	64.9	58.6	45.5			



After degassing Pt in high vacuum,  $\delta_0 = 0$  if  $4 \leq V_{rp} \leq 500$  volt (95).

$(N_i)_\varphi = (N_i)_0 \cos \varphi$  = number emerging at angle  $\varphi$ . For Pt and  $V_{rp} \leq 50$  volt,  $(N_i)_\varphi$  is a maximum when  $\varphi = 0$ , if  $\theta \leq 60^\circ$  (89). Early results for greater velocities are unreliable, see (66, 84).

If  $\theta = 0$  for all primary electrons,  $N_i$  varies with  $V_{rp}$  as shown in Figs. 4, 5, 6. For Fe, see (32). Earlier results were less reliable and do not agree with these curves, see (7, 8, 12, 20, 27, 38, 45, 48, 56, 57).

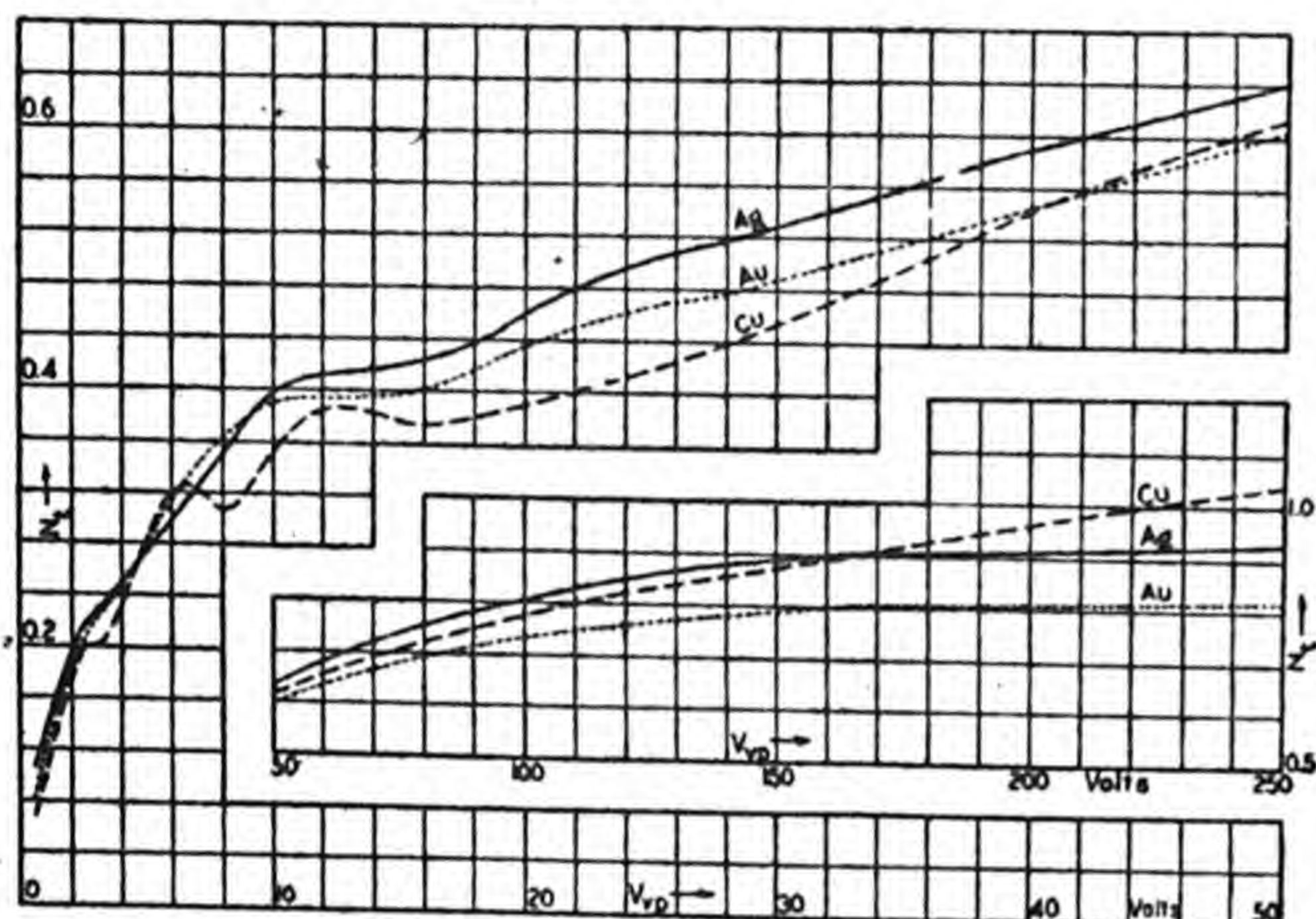


FIG. 4.—Variation in emission ( $N_i$ ) with the velocity of the primary electrons: Ag, Au, Cu (25).

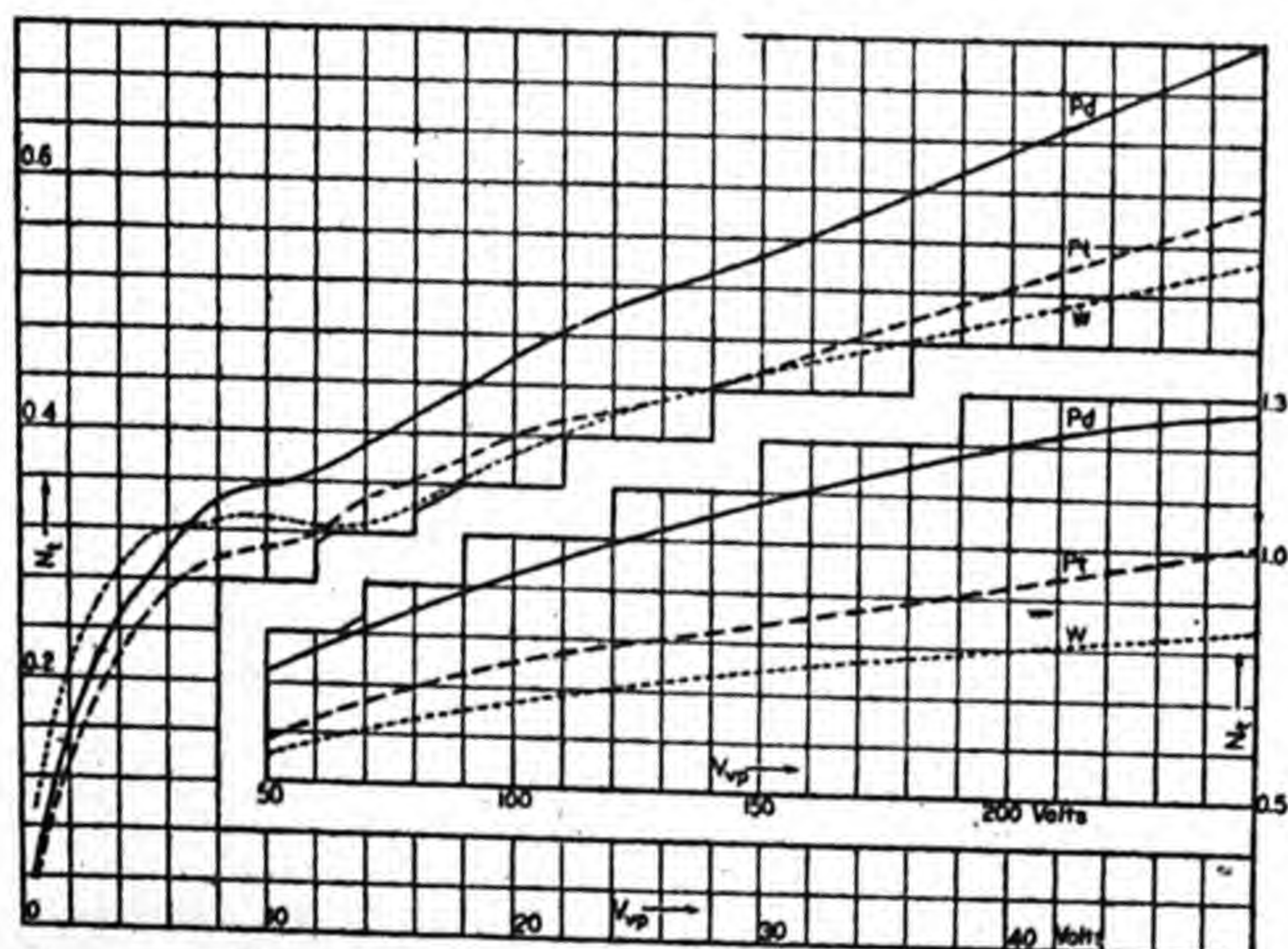


FIG. 5.—Variation in emission ( $N_i$ ) with the velocity of the primary electrons: Pd, Pt, W (25).

For many metals,  $N_i$  is a maximum  $(N_i)_m$  at some value of  $(V_{rp})_m$  or  $V_{rp}$ .

Metal..	Ag, Al, Au	Au	Cu	Cu	Cu, Fe	Fe	Fe	Mo	Ni	W
$(V_{rp})_m$	200	330	240	750*	200	410†	348	356	455	700 v
$(N_i)_m$		1.14	1.32				1.3	1.3	1.3	1.45
Lit.....	(88)	(75)	(75)	(64)	(88)	(73)	(74)	(74)	(74)	(75)

\*  $N_i$  decreases slightly at higher velocities (11).

† At  $V = 1500$  volt,  $N_i$  is only 0.74  $(N_i)_m$ .

### VELOCITIES OF SECONDARY ELECTRONS

The lower curves ( $V_{rp} > 20$  volt) of Fig. 7 are typical of all metals (31). If  $v_p/c = 0.55$  to  $0.65$ , the average velocity of the

secondaries from a pure liquid is greater than that from a pure metal; the velocity increases slightly as the atomic (molecular) weight is reduced (1). If  $v_p/c = 0.9$  (ca.  $V_{rp} = 660$  kilovolt), the velocities of the secondaries are distributed over a large range, but the average corresponds to ca. 1 kilovolt. For blackened metal surfaces, see (15).

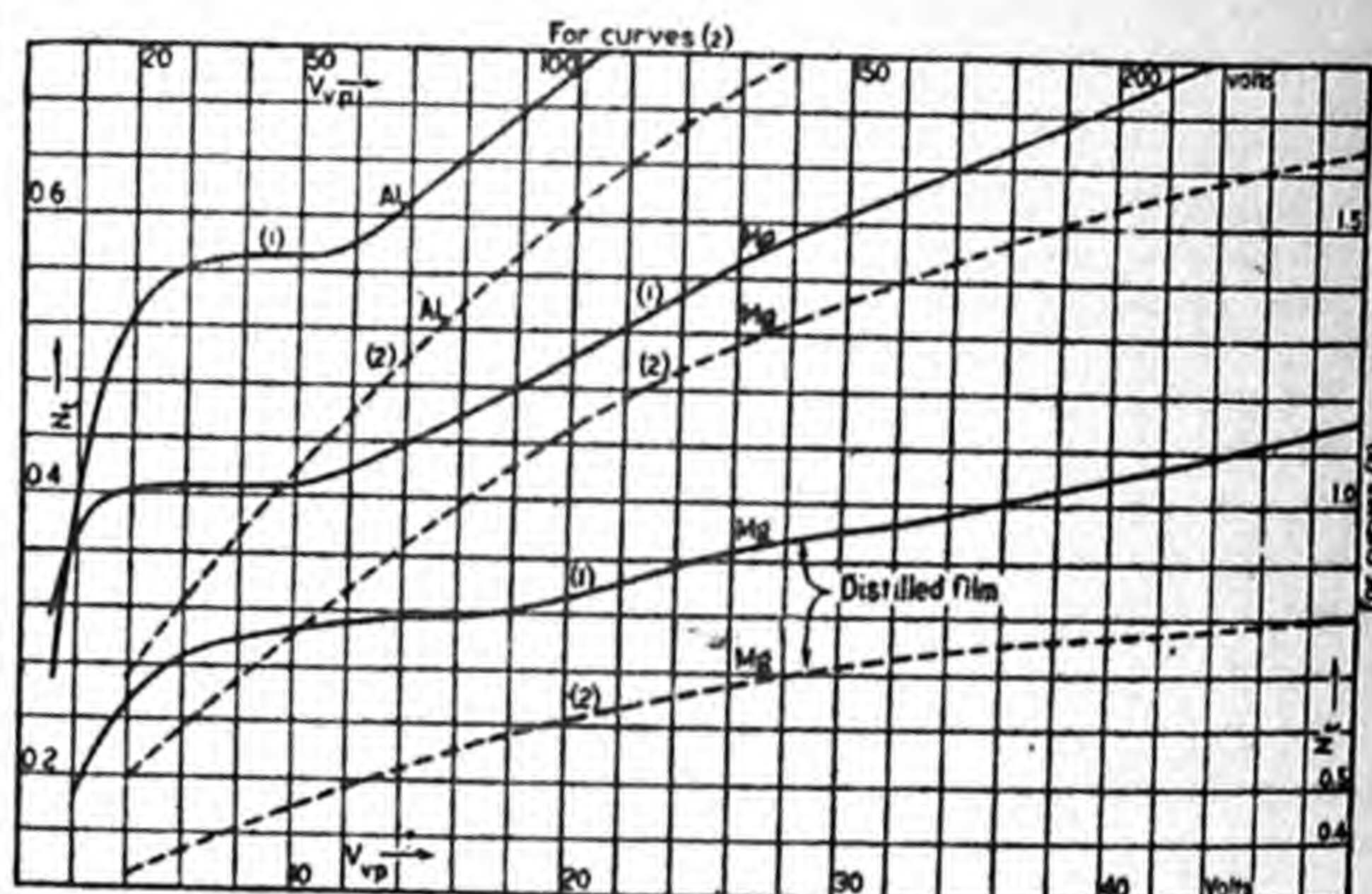


FIG. 6.—Variation in emission ( $N_i$ ) with the velocity of the primary electrons: Al, Mg (25).

Curves (1) are referred to scales at left and below; curves (2) to scales at top and right. The two lower curves refer to Mg which has been distilled upon the target.

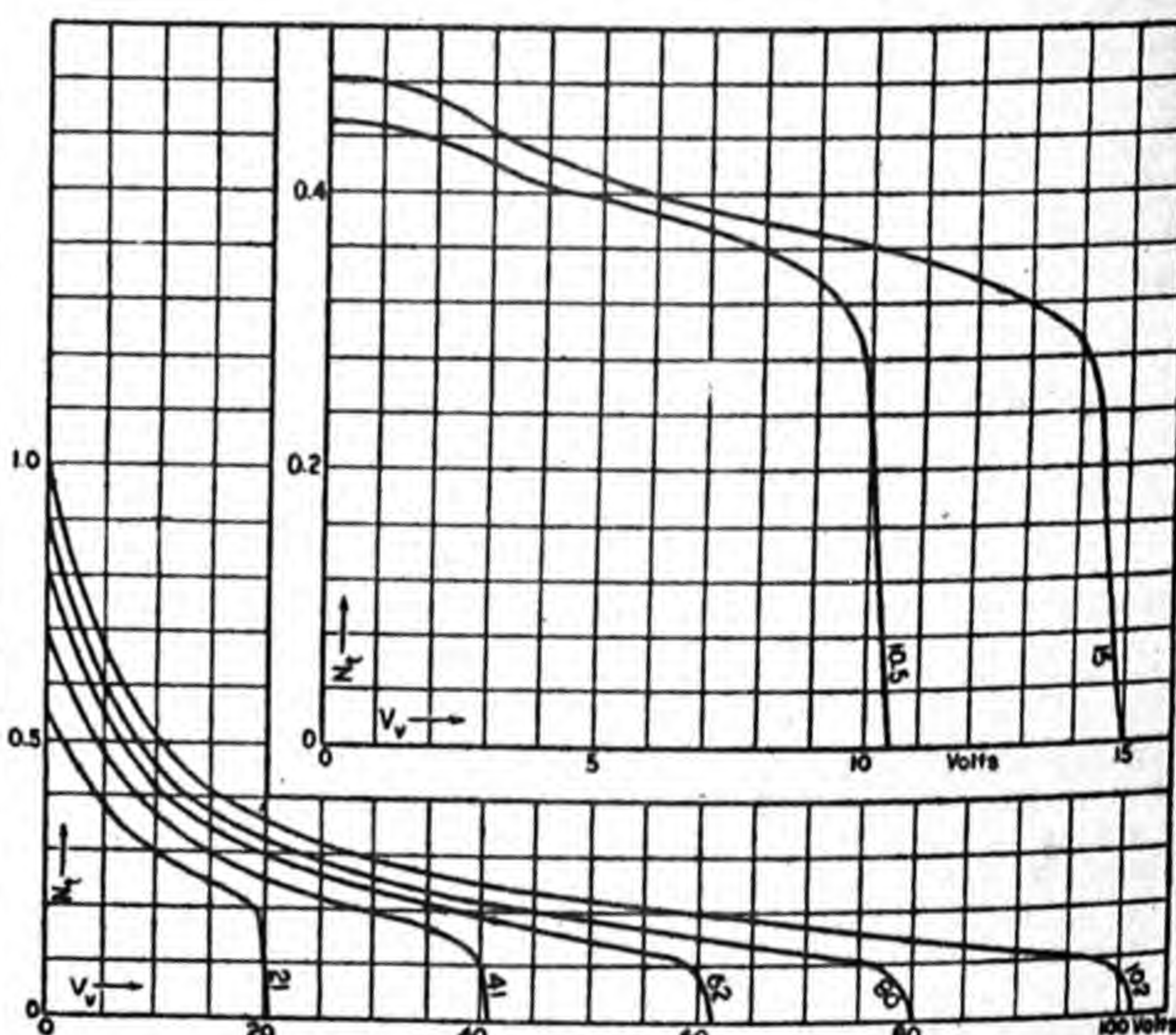


FIG. 7.—Velocities of secondary electrons (25).

Ordinates indicate the number ( $N$ ) of secondary electrons, per primary, which have velocities greater than that indicated by the corresponding abscissae ( $V_i$ ). Each curve intersects the axis of abscissae at the point  $V_{rp}$  which defines the velocity of the primary electrons to which the curve refers.

TABLE 9.—ELECTRON EMISSION EXCITED BY IMPACT OF SLOWLY MOVING POSITIVE IONS

For emission from  $\alpha$ -ray impact, see Vol. I, p. 365; for absorption of positive ions, see (99)

Even if  $V_{rp} =$  several hundred volts, the velocity of the emitted electrons is low,  $V_e = 0$  to 30 volt (3, 4, 36, 37); for those emitted from second side of thin film of Au,  $V_e < 40$  if  $V_{rp} \leq 21$  750 volt, and for 75% of them  $V_e < 1.25$  if  $V_{rp} = 6$  350 volt (40).

As  $V_{rp}$  is reduced, the number ( $N^-$ ) of emitted electrons approaches 0, asymptotically in the case of solids and more abruptly in the case of gases;  $N = 0$  if  $V_{rp} < (V_{rp})_0$ ; data for



$(V_{ep})_0$  are discordant. Preheating reduces  $N^-$ . Before heating,  $(V_{ep})_0 = 20$  to 30 volt for all solids (3, 4), = 20 volt for Pt (44). After heating, as follows; unit of  $V = 1$  volt:

Metal	$(V_{ep})_0$	$N_{1-}^*$	$N_{1+}^*$	$V_{e1-}$	ions†	Lit.
Al.....	200	0.07	0	<1	K	(50)
Ni.....	300	0.042	<0.02	<1	K	(50)
Ni.....	50†	†	†		AlPO <sub>4</sub>	(52)
Mo.....	600	0.038	<0.02	<1	K	(50)

\* Values for  $V_{ep} = 1000$ .

† Source of ions bombarding target.

‡ After heating Ni to 1000°C;  $N_{1-} = 1.5(V_{ep})^{1/2}(10)^{-3}$  if  $V_{ep} \leq 380$ ;  $N_{1+}$  is great;  $v_{1+}$  is small. Data appear to be less reliable than those of (50).

For gases the following values of  $(V_{ep})_0$  are recorded; unit = 1 volt: Impact of +Na on Hg vapor (90),  $\leq 40$ , air (10)  $< 6$ , +H on H<sub>2</sub> gas (42)  $> 925$  [earlier and much lower values ( $\leq 18$  (79),  $< 6$  (10) are attributed to emission from walls of chamber], He (44)  $> 200$ , for any gas  $(V_{ep})_0$  is of same order as for electronic impact (72). For values of  $(V_{ep})_0$  for electronic impact, see p. 69.

For gases,  $n(=dN/dx)$  increases with the velocity and is proportional to the pressure, temperature being constant. For impact of +H ions on H<sub>2</sub> at 1 atm. and room (?) temperature:

$V_{ep}$ .....	5	18	25	31	Unit = 1 kilovolt
$n$ (4, 5).....	76	152	228	260	Unit = 10 <sup>6</sup>

For solids,  $N_1$  increases with the velocity and with the angle of incidence; for thin films,  $N_1$  is independent of thickness (40). For Au foil, thickness not stated, unit of  $V_{ep} = 1$  kilovolt:

$V_{ep}$ .....	5	10	15	20	25
$N_1$ .....	0	0.1	1.0	3.0	6.0

The number of + ions emitted is ca.  $N_2/3$ ; for double thickness, divide  $N_2$  by 10 (40). For insulators,  $N$  is less than for metals (54). The law of absorption of H canal rays in thin metal foil

is similar to that for  $\alpha$ -rays (42) (see Vol. I, p. 368). Unit of  $V_{ep} = 1$  volt. Metals not gas-free. Signs -[+] indicate electrons [positive ions].

$V_{ep}$	$N_{1-}$	$N_{1+}$	$V_{ep}$	$N_{1-}$	$N_{1+}$
Target = Cu			Target = Brass (3, 4)		
+ ions = Na and Al* (21)			+ ions = H		
400	0.049		300	2.0	
2 000		0.07	5 000	3.45	
8 000	1.5		18 000	4.8	
38 000	2.8	0.10	25 000	5.4	
48 000	1.4		31 000	5.4	
+ ions = H (35)					
15 000	0.89	0.083			
31 000	1.36	0.15			

$V_{ep}$	1 000 $N_{1-}$			$V_{ep}$	1 000 $N_{1-}$		
	K	Li	Rb		K	Li	Rb
Target = Pt (22)				Target = Al (22)			
74		6		74	4		
115			1.6	125	8		
146	4.5	13	2	146	11		
190	7	17	3	177		10	
235			5	215	18	20	
250	12.5			275	25	58	8
265		19		340	37	93	14
275	14	7		375	47		
300	24			450	67	138	22
350	17		8	475	80		
360		26		535		214	36
390		30		560	92		
400	19.5		9				
475	20.7	36					
560	25	43	12				

\* Ions from heated phosphates of Na and Al.

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Allen, *2*, 29: 177; 09. (2) Allen, *2*, 29: 276; 10. (3) Baerwald, *8*, 41: 643; 13. 42: 1287; 13. 60: 1; 19. (4) Baerwald, *8*, 66: 167; 21. (5) Baerwald, *88*, 14: 867; 12. 16: 789; 14. (6) Baerwald, *8*, 76: 829; 25. (7) v. Baeyer, *88*, 10: 96; 08. (8) v. Baeyer, *88*, 10: 953; 08. 63, 10: 176; 09. (9) v. Baeyer, *63*, 13: 485; 12. 200, 11: 66; 14.
- (10) v. Bahr and Franck, *88*, 16: 57; 14. (11) Baltruschat and Stark, *63*, 23: 403; 22. (12) Barber, *2*, 17: 322; 21. (13) Baxman, *Diss.* Halle, 1911.
- (14) Becker, *8*, 17: 381; 05. 171, 19A, 16; 10. *8*, 75: 435; 24. 78: 209; 25. (15) Becker, *8*, 78: 228, 253; 25. (16) Block, *8*, 33: 559; 12. (17) Brode, *5*, 109: 397; 25. (18) Brode, *2*, 25: 636; 25. (19) Campbell, *5*, 17: 180; 09.
- (20) Campbell, *5*, 22: 276; 11. 24: 527; 12. 25: 803; 13. 28: 286; 14. 29: 369; 15. (21) Campbell, *5*, 29: 783; 15. (22) Cheney, *2*, 10: 335; 17.
- (23) Compton and Van Voorhis, *2*, 27: 724; 26. (24) Crowther, *5*, 80: 186; 08. (25) Crowther, *Ions, electrons and ionizing radiations*. New York, Longmans, 1924. (26) Crowther and Schonland, *5*, 100: 526; 22. (27) Dadourian, *2*, 14: 434; 19. (28) Danyesz, *5*, 80: 241; 13. (29) Davisson and Kunsman, *2*, 22: 242; 23.
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## PHOTOCONDUCTIVITY AND PHOTO-ELECTROMOTIVE FORCE

A. LL. HUGHES

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Photoconductivity.	Photoconductibilité.	Photoelektrischeleitfähigkeit.	Fotoconducibilità.....	66
Photo-emf.	Photo-fem.	Photoelektromotorische Kraft.	Foto-fem.....	66
Minerals exhibiting photocon-	Minéraux présentant le phéno-	Mineralien mit Photoelektri-	Mineralien che presentano	
ductivity.	mène de la photoconducti-	scheleitfähigkeit.	fotoconducibilità.....	66
	bilità.			
Solutions exhibiting photocon-	Solutions présentant le phéno-	Lösungen mit Photoelektrische-	Soluzioni che presentano	
ductivity.	mène de la photoconducti-	leitfähigkeit.	fotoconducibilità.....	66
	bilità.			
Wave-length for maximum pho-	Longueur d'onde pour la photo-	Wellenlänge für die maximale	Lunghezza d'onda per la	
toconductivity.	conductibilité maximum.	Photoelektrischeleitfähigkeit.	fotoconducibilità mas-	
			sima.....	66

**Photoconductivity.**—If, apart from temperature change, an illumination of a substance alters its resistivity, the substance is said to exhibit photoconductivity. So far as known, the alteration is always a decrease in the resistivity. The effect varies with the wave-length of the light and that wave-length ( $\lambda_m$ ) at which the effect is a maximum is the most important and definite characteristic of the substance with reference to its photoconductive properties. The amount the resistivity of a substance is decreased by a given illumination varies greatly from specimen to specimen, being profoundly modified by small amounts of impurities.

**Photo-emf.**—If argentite ( $\text{Ag}_2\text{S}$ ) is provided with two similar metallic electrodes, the illumination of one of the contacts causes it to acquire a positive potential with reference to the other. The most effective illumination is  $\lambda = \text{ca. } 10\,000 \text{ \AA}$ ; with increasing intensity of illumination, the emf reaches a limiting value (0.013 volt) at 600 meter-candle (13). If two electrodes of the same metal are immersed in an electrolyte and one of them is illuminated, it acquires a potential which differs from that of the unilluminated electrode. For Cu, Hg, and Pt, the illuminated electrode is the more positive; for Ag and Au, the opposite is true. The nature of the electrolyte is unimportant (1).

TABLE 1.—MINERALS EXHIBITING PHOTOCONDUCTIVITY (2)

Out of 175 substances examined with light from an electric arc, the following 19 exhibited photoconductivity. The magnitudes of the effect are indicated roughly by the symbols: s = small, m = medium, g = great, vg = very great.

$\text{Ag}_3\text{AsS}_4$	Proustite	g
$\text{Ag}_3\text{AsS}_4$	Pearceite	m
AgI	Iodyrite	m
$\text{Ag}_2\text{O}$	Silver oxide	m
$\text{Ag}_2\text{S}$	Acanthite	g
$\text{Ag}_2\text{S}$	Argentite	g
$\text{AgSbS}_3$	Miargyrite	m
$\text{Ag}_3\text{SbS}_4$	Pyrargyrite	m
$\text{Ag}_3\text{SbS}_4$	Stephanite	m
$\text{Ag}_3\text{SbS}_4$	Polybasite	m
$\text{Bi}_2\text{S}_3$	Bismuthinite	vg
$\text{Cu}_2\text{O}$	Cuprite	m
$(\text{Cu}_2, \text{Pb})_2\text{Sb}_2\text{S}_6$	Bournonite	g
$\text{MoS}_2$	Molybdenite	m
$\text{PbS}$	Galena	m
$\text{Pb}_2\text{Sb}_2\text{S}_4$	Jamesonite	m
$\text{Pb}_2\text{Sb}_2\text{S}_4$	Boulangerite*	g
$\text{Sb}_2\text{S}_3$	Stibnite	s
Se	Selenium	m

\* Embrithite.

TABLE 2.—SOLUTIONS EXHIBITING PHOTOCONDUCTIVITY (14)  
Solvent is *n*-hexane ( $\text{C}_6\text{H}_{14}$ )

Formula	Substance	Formula	Substance
$\text{C}_{10}\text{H}_8\text{O}_4$	Naphthazarine	$\text{C}_{14}\text{H}_{10}$	Anthracene*
$\text{C}_{10}\text{H}_8\text{O}$	$\alpha$ -Naphthol	$\text{C}_{14}\text{H}_{10}$	Phenanthrene
$\text{C}_{10}\text{H}_8\text{O}$	$\beta$ -Naphthol	$\text{C}_{14}\text{H}_{12}$	Stilbene
$\text{C}_{10}\text{H}_9\text{N}$	$\alpha$ -Naphthylamine	$\text{C}_{15}\text{H}_{12}$	Methylantracene
$\text{C}_{14}\text{H}_8\text{O}_4$	Quinizarin	$\text{C}_{15}\text{H}_{12}$	Chrysene

\* Conductivity increased 1 000 times by illumination with light of  $\lambda = 2\,250$ .TABLE 3.—WAVE-LENGTH ( $\lambda_m$ ) FOR MAXIMUM PHOTOCONDUCTIVITY  
Unit of  $\lambda_m = 1 \text{ \AA} = 10^{-8} \text{ cm}$ ;  $t = ^\circ\text{C}$ ;  $t_r = \text{room temperature}$ 

Formula	Substance	$\lambda_m$	$t$	$\lambda_m$	$t$	Lit.
AgBr		4 600	$t_r$			(7)
AgCl		3 800	$t_r$			(7)
AgI		4 700	$t_r$	5 000	$t_r$	(7)
$\text{Ag}_2\text{S}$	Acanthite	13 500	22	4 100	$t_r$	(4)
		12 000	-153			(4)
$\text{Ag}_2\text{S}$	Argentite	13 500	22	4 100	$t_r$	(4)
		11 100	-153	11 200	-110	(4)
$\text{Ag}_3\text{SbS}_4$	Pyrargyrite	6 300	15	6 300*	-180	(6)
$\text{Bi}_2\text{S}_3$	Bismuthinite	10 800	-166	6 400	-166	(9)
$\text{Cu}_2\text{O}$	Cuprous oxide	2 800†	$t_r$	6 250	$t_r$	(12)
$(\text{Cu}_2, \text{Pb})_2\text{Sb}_2\text{S}_6$	Bournonite	9 500‡	$t_r$	5 500‡	$t_r$	(6)
I	Iodine	5 400	$t_r$			(5)
$\text{MoS}_2$	Molybdenite	18 000	15	10 200§	15	(8)
		8 500	15	7 000	15	(8)
		8 500	-180			(8)
$\text{PbI}_2$		5 200¶	$t_r$	4 500¶	$t_r$	(7)
$\text{Sb}_2\text{S}_3$	Stibnite	7 500	15	6 800	-180	(11)
Se	Selenium	7 000	$t_r$	5 500	$t_r$	(10)
		7 000	15	6 000	-180	(11)
$\text{TlBr}$		4 130**	$t_r$			(7)
$\text{TlCl}$		3 650**	$t_r$			(7)
$\text{TlI}$		4 130**	$t_r$			(7)
	Thalofide††	10 000	$t_r$			(3)

\* Maximum sharper than at higher temperature.

† Principal maximum.

‡ Maximum is ill-defined.

§ Strongest at this temperature.

|| Weak at this temperature.

¶ Sharp maximum.

\*\* Width of peak ca. 800 Å.

†† Thallium oxyarsulfide; sensitivity ranges from  $\lambda = 4\,000$  to  $\lambda = 12\,000$ , where it ends abruptly.

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## PHOTOEMISSION OF ELECTRONS

A. LL. HUGHES

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Photoelectric thresholds.	Seuils photoélectriques.	Photoelektrische Schwellenwerte.	Frequenza limite.....	67
Wave length for maximum sensitivity.	Longueur d'onde pour la sensibilité maximum.	Wellenlängen maximaler Empfindlichkeit.	Lunghezza d'onda per la sensibilità massima.....	68
Variation of sensitivity with wave-length (illustrative).	Variation de la sensibilité avec la longueur d'onde (explicatif).	Änderung der Empfindlichkeit mit der Wellenlänge (erläuternd).	Variazione della sensibilità con la lunghezza d'onda (esemplificazione).....	68
Relative values of current: pure substances, heterochromatic illumination.	Valeurs relatives du courant: substances pures, éclaircissement hétérochromatique.	Relativer Wert des Stromes: reine Stoffe, verschiedenfarbige Beleuchtung.	Valori relativi della corrente: sostanze pure, illuminazione eterocromatica.....	68
Sensitivity of aqueous solutions and alloys.	Sensibilité des solutions aqueuses et des alliages.	Empfindlichkeit wässriger Lösungen und Legierungen.	Sensibilità di soluzioni acquose e di leghe.....	69

When a substance is illuminated by light of a sufficiently high frequency it emits electrons; this is the photoelectric effect. The photoelectric threshold ( $\lambda_0$ ) is the longest wave-length capable of producing the effect. For solids and liquids,  $\lambda_0$  depends upon surface conditions; observed values vary widely (8, 26, 42, 47, 53, 61, 64, 65). The strength of the photoelectric current from an illuminated surface is proportional to the intensity of the incident light (6, 7, 12, 27, 28, 31, 50) and varies with the wave-length, frequently passing through a maximum at a certain wave-length ( $\lambda_m$ ) characteristic of the substance. A substance may have a

variation. For all these observations the metals were in a vacuum.

With the alkali metals, measurable currents have been obtained (7) with an energy flow of  $3 \times 10^{-9}$  erg/cm<sup>2</sup> sec of blue, and of  $2 \times 10^{-7}$  erg/cm<sup>2</sup> sec of orange, light. The greatest charge liberated per calorie of incident radiation is of the order of 0.01 coulomb; for Pt  $\lambda$  2000 the charge liberated is  $3.0 \times 10^{-5}$  coulomb/calorie, for Al  $\lambda$  2200 it is  $22.5 \times 10^{-5}$ , for Na  $\lambda$  3700 it is  $171 \times 10^{-6}$  and for Na  $\lambda$  2300 it is  $330 \times 10^{-6}$ , same unit for all (49); see also (56).

If the light is plane polarized and is incident obliquely upon the surface, the photoelectric current from some substances and at a certain wave-length ( $\lambda_s$ ) is much greater when the electric vector  $E$  lies in the plane of incidence than when it is perpendicular to it. Such a substance is said to exhibit a "selective" effect at  $\lambda_s$ ; in unpolarized light  $\lambda_m$  coincides with  $\lambda_s$ . Very few metals having a  $\lambda_m$  have also a  $\lambda_s$  (21). The alkali metals exhibit a selective effect only when in thin films and of the alloys, only NaK<sub>2</sub> exhibits it (21).

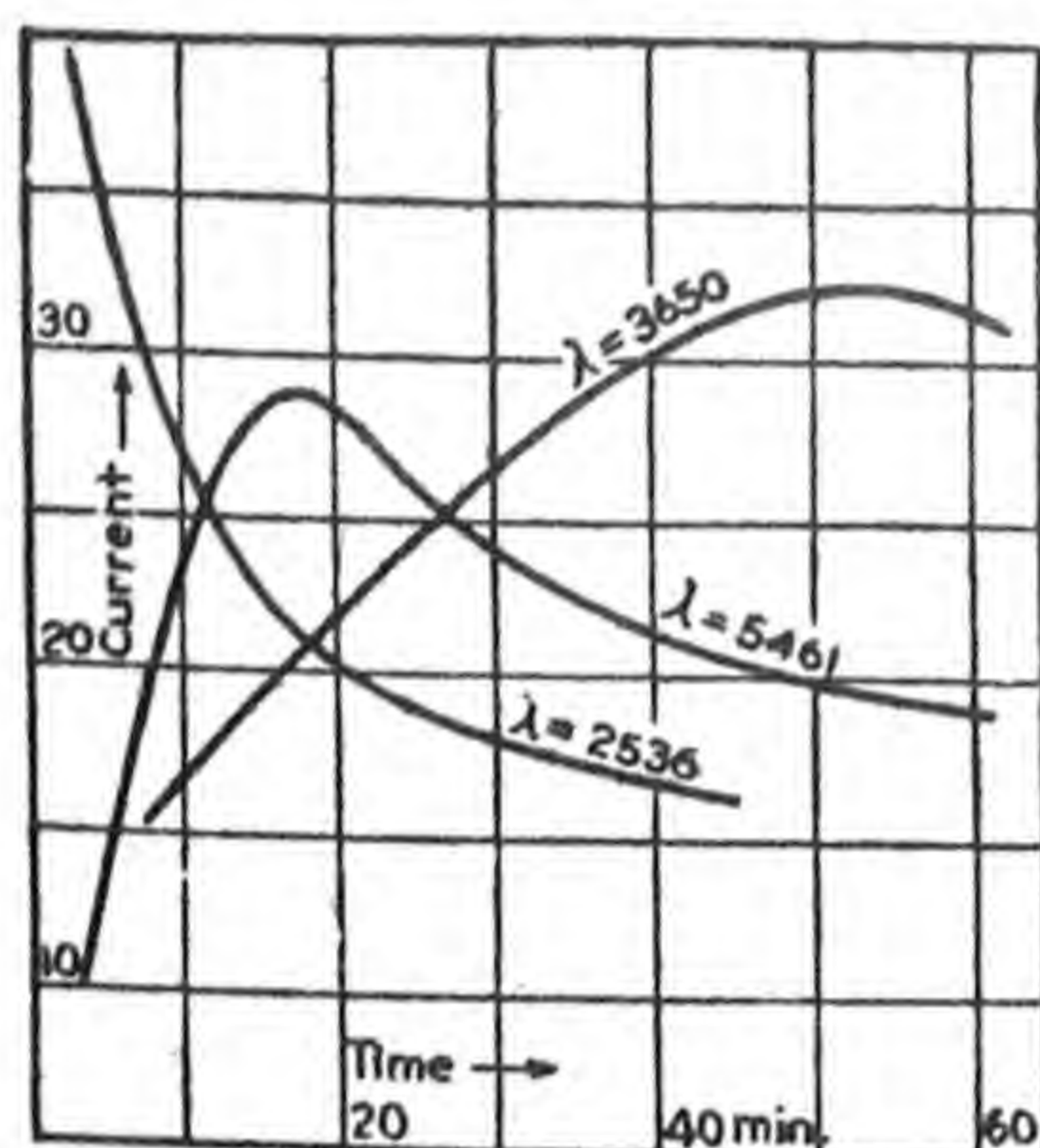


FIG. 1.

FIG. 1.—Variation of photoelectric current with age of surface (35). Na shaved in *vacuo*; age measured from time of shaving; current expressed in arbitrary units; unit of  $\lambda = 1 \text{ Å} = 10^{-8} \text{ cm}$ .

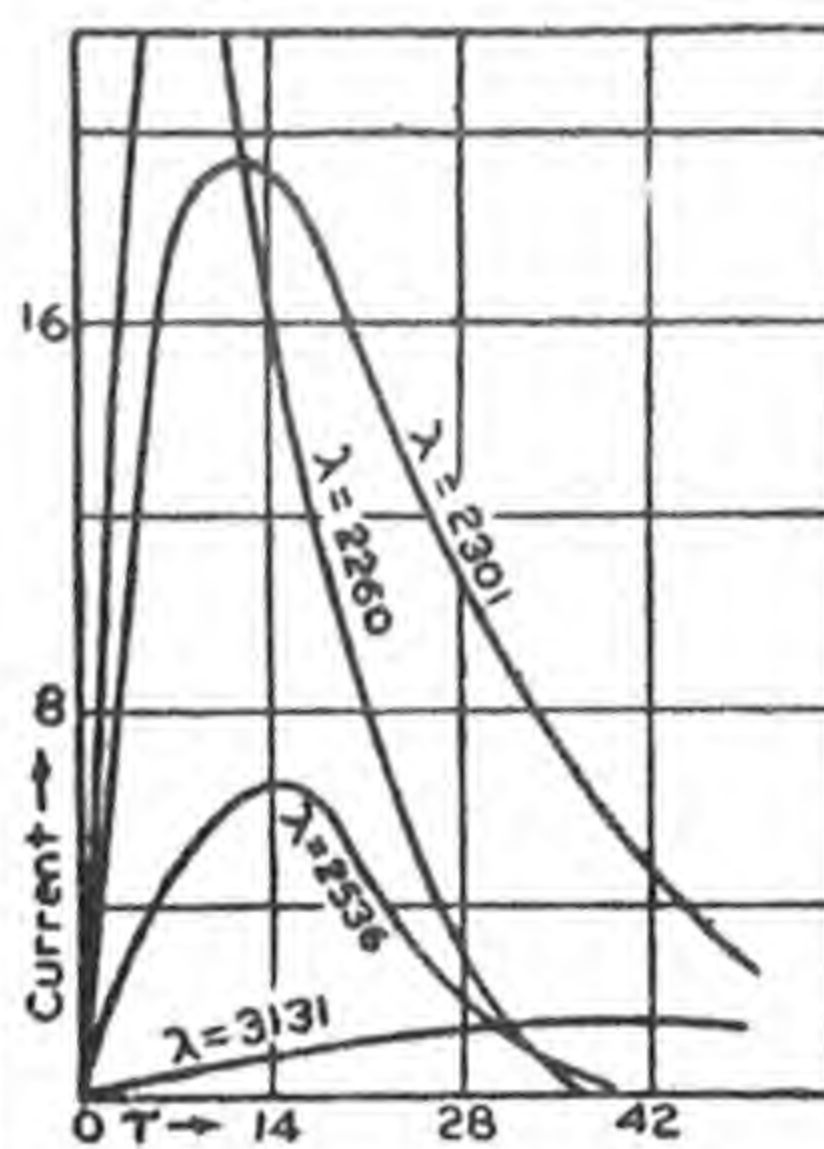


FIG. 2.

FIG. 2. Variation of photoelectric current with thickness ( $\tau$ ) of film (59).

Pt deposited in *vacuo* by evaporation from wire to a quartz ( $\text{SiO}_2$ ) plate; current, expressed in arbitrary units, per unit energy of radiation; unit of  $\tau = 1 \text{ mμ} = 10^{-7} \text{ cm}$ , of  $\lambda = 1 \text{ Å} = 10^{-8} \text{ cm}$ .

$\lambda_m$  without exhibiting a "selective" photoelectric effect, as presently defined. The current varies with the age of the surface (35) (see Fig. 1), and depends upon the gas content; the evidence regarding its possible variation with the temperature is somewhat conflicting; for Al in range 20 to  $-180^\circ\text{C}$  (37, 38), Ag, Au, Fe 15 to  $125^\circ\text{C}$  (36), K 20 to  $110^\circ\text{C}$  (4), Mg 15 to  $125^\circ\text{C}$  (36), Na 20 to  $110^\circ\text{C}$  (4) and 20 to  $-180^\circ\text{C}$  (2), NaK alloy 20 to  $110^\circ\text{C}$  (4), Ni, Pb 15 to  $125^\circ\text{C}$  (36), Pt 60 to  $300^\circ\text{C}$  (62), and Sb, Zn 15 to  $125^\circ\text{C}$  (36) no variation was observed, but Ives (20) found that the current from K and from Na decreased as the temperature was reduced from 0 to  $-180^\circ\text{C}$ , the reduction being 20% for blue and 45% for yellow light; the lower the temperature, the more rapid was the

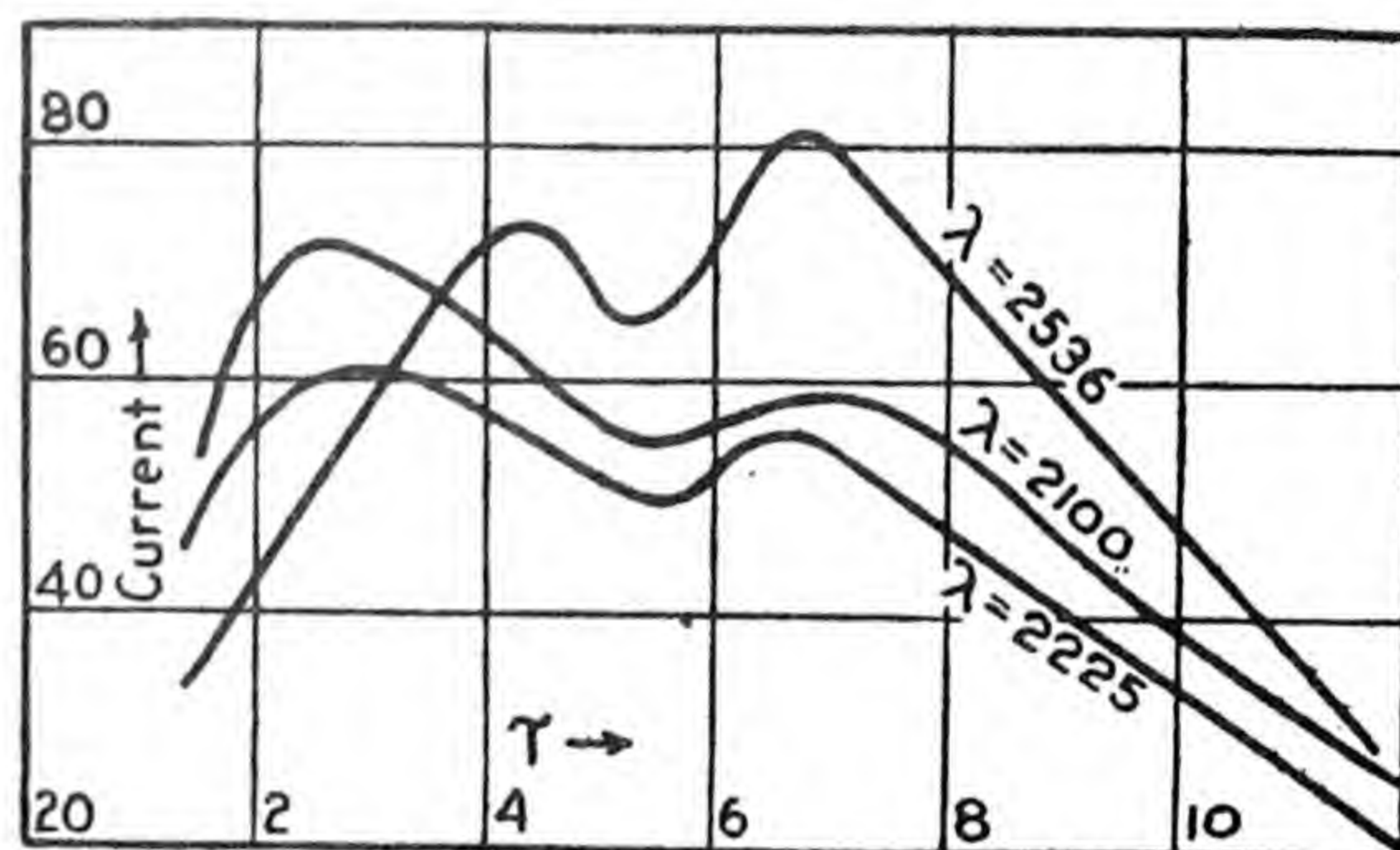


FIG. 3.—Variation of photoelectric current with thickness ( $\tau$ ) of film (3).

Pt deposited by cathode sputtering; current expressed in arbitrary units; unit of  $\tau = 1 \text{ mμ} = 10^{-7} \text{ cm}$ , of  $\lambda = 1 \text{ Å} = 10^{-8} \text{ cm}$ .

Evidence derived from thin films (19, 41, 43) now favors the view that, at instant of liberation, photoelectrons are emitted in all directions in equal numbers and with equal velocities. For variation of photoelectric current with thickness of film, see Figs. 2, 3.

## TABLE 1.—PHOTOELECTRIC THRESHOLDS

a[b] = surface mechanically cleaned before [after] being placed in vacuum; c = distilled in vacuum; d = data for tiny drops; e = special care taken to outgas the substance in vacuum; f = surface newly formed in vacuum; g = data for gas phase. Unit of  $\lambda_0 = 1 \text{ Å} = 10^{-8} \text{ cm}$ .



TABLE 1.—(Continued)

Element	$\lambda_0$	Lit.	Element	$\lambda_0$	Lit.
Ag.....	3390a	(13)	K $\ddagger$ —(Cont'd)	>6000	(67) *
	3250	(60)		<7000	(67)
Al.....	4770a	(48)	Li.....	5800b	(34)
	3342a	(14)	Mg**	3820a	(48)
	3595a	(13)	Na.....	5830a	(48)
As.....	2360c	(17)		6800b	(34)
Au.....	*		Ni...*	3050a	(13)
Bi.....	3300a	(48)	Pb.....	3115c	(17)
	3225c	(17)		2980a	(13)
	2980a	(13)	Pt††.....	2800a	(48)
C†.....	2615a	(13)		2780a	(13)
Ca.....	3700c	(17)		2840	(60)
	4000a	(13)		2570e	(24)
Cd.....	3140c	(17)	S.....	<3300	(10)
	3130a	(13)		<2400d	(23)
Cl.....	<1250g	(33)		>2200d	(23)
Cs.....	3180g	(29)	Se.....	2200c	(17)
Cu.....	3000a	(48)		2670a	(13)
	3050a	(14)	Sn.....	3620a	(48)
	2665a	(13)		3050a	(14)
Fe, cf. (2.5)...	3050a	(14)	Th.....	3185a	(13)
	2870a	(13)	W.....	3465a	(13)
Hg.....	>1800g†	(58)		2615a	(13)
	2735f	(22)		2300e	(11)
Ir.....	*		Zn††.....	3760a	(48)
K $\ddagger$ .....	>2800g	(66)		3200a	(14)
	<3100g	(66)		3016c	(17)
	4360¶	(47)		3425a	(13)

Formula	Substance	$\lambda_0$	Lit.
CuO	Air.....	ca. 1300	(15,49)
SnCl <sub>4</sub>		2500	(34)
Zn(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub>	Tin tetrachloride.....	<1800	(16)
CS <sub>2</sub>	Zinc ethyl.....	<1800	(16)
C <sub>6</sub> H <sub>7</sub> N	Carbon disulfide.....	<1800	(16)
C <sub>10</sub> H <sub>9</sub> N	Aniline.....	>1850	(54)
C <sub>12</sub> H <sub>11</sub> N	$\alpha$ -Naphthylamine.....	>1850	(57)
C <sub>12</sub> H <sub>12</sub>	Diphenylamine.....	>1850	(57)
C <sub>12</sub> H <sub>12</sub>	Diphenylmethane.....	>1850	(57)
C <sub>14</sub> H <sub>10</sub>	Anthracene.....	>1850	(57)
	Anthracene.....	2170	(18)
	Anthracene.....	2250	(63)
	Anthracene in hexane.....	2250	(63)
	Oil (watch-oil).....	<2150	(23)
	Paraffin.....	<2150	(23)
	Shellac.....	<2200	(23)
BaO	(At 420°C, $\lambda_0$ = 3880) 20°C.	2860	(24)
CaHg <sub>2</sub>	Ca amalgam.....	3500	(46)
SrO	(At 420°C, $\lambda_0$ = 3880) 20°C.	2860	(24)

\*  $\lambda_0$  is not given, but observations (30) indicate that it is independent of temperature between 20 and 860°C.

† For soot (lampblack)  $\lambda_0$  independent of temperature between 0 and -180°C (32).

‡ Does not agree with value expected from ionizing potentials.

§ Ives (29) found  $\lambda_0$  shifted from 7000 to 6200 as  $t$  changed from 20 to -180°C.

\*\* For newly distilled Mg,  $\lambda_0$  shifted from 3500 to 5500 in 24 hr. in high vacuum (46).

|| Agrees with value expected from ionizing potential.

¶ After repeated distillations in very high vacuum  $\lambda_0$  < 3300 (65), others under equally good and similar conditions find  $\lambda_0$  = 4360 (47).

†† After heating to 900°C for 8 hr,  $\lambda_0$  = 2700; after heating to 1400°C and outgassing,  $\lambda_0$  < 1850 (61).  $\lambda_0$  is independent of temperature (24), at least for range 20 to 860°C (30). For Pt-black,  $\lambda_0$  independent of temperature for range 0 to -180°C (32).

‡‡ For new surfaces prepared in highest obtainable vacuum  $\lambda_0$  < 1850 (26).

§§ Shifts to 6000 in course of a few hr; observed in high vacuum (46).

TABLE 2.—WAVE-LENGTH ( $\lambda_m$ ) FOR MAXIMUM PHOTOELECTRIC SENSITIVITY

$B$  = breadth = spectral range over which the photoelectric effect is unusually great. For example: For K,  $\lambda_m$  = 4400,  $B$  = 2500; that is, the effect is unusually great from ca.  $\lambda$  = 3150 to 5650. The substance was in a vacuum (v) or in argon (A). Unit of  $\lambda_m$  and of  $B$  = 1 Å = 10<sup>-8</sup> cm.

Substance	Gas	$\lambda_m$	$B$	Lit.	Substance	Gas	$\lambda_m$	$B$	Lit.
Ba.....	v	2800		(44)	KTI <sub>2</sub> .....	v	3000	3200	(44)
Cs.....	v	4800		(21)	Li.....	v	2800		(44)
	A	5390		(52)		A	4050		(52)
CsH.....	A	5400		(52)	Na.....	A	4190		(52)
CsK <sub>2</sub> .....	v	4800		(21)		A	4400		(55)
CsNa <sub>2</sub> .....	v	4800		(21)		v	3400	3200	(44)
CsRb <sub>2</sub> .....	v	4800		(21)	NaH.....	A	4270		(52)
K.....	A	4400		(52, 55)		A	4400		(55)
	v	4400	2500	(44)	NaRb <sub>2</sub> ...	v	4500		(21)
	v	4400	2100	(9)	Rb.....	A	4700		(52)
	v	4000		(21)		A	4560		(55)
KH.....	A	4560		(52)		v	4700	1800	(44)
	A	4400		(55)		v	4800		(9)
KHg <sub>2</sub> .....	v	3800	2900	(44)	RbH.....	A	4810		(52)
KNa <sub>2</sub> .....	v	3900	2900	(44)		A	4560		(55)
KRb <sub>2</sub> .....	v	4500		(21)					

TABLE 3.—ILLUSTRATING VARIATION OF PHOTOELECTRIC SENSITIVITY WITH WAVE-LENGTH ( $\lambda$ ) OF INCIDENT LIGHT

For each metal the unit is chosen so as to make the sensitivity 100 for a certain wave-length. When light is not monochromatic,  $\lambda_{min}$  = approximately the shortest  $\lambda$  in the light used. Unit of  $\lambda$  = 1 Å = 10<sup>-8</sup> cm (45).

$\lambda$	Bi	Cd	Pb	Sn	Tl
2300	100	100	100	100	100
2540	56.3	59.2	50.4	55.2	62.1
3130	<1	<1	1.6	1.4	5.8
3650	0	0	<1	<1	<1

Light source is Al spark, filtered (39)

Filter	$\lambda_{min}$	CuO	Ice	Water
CaF <sub>2</sub> , Fluorite*	1250	100	100	100
SiO <sub>2</sub> , Quartz.....	1450	27	40	15
SiO <sub>2</sub> + Air.....	1770	22	50	11
CaCO <sub>3</sub> , Calcite.....	2200	<1	0.02	0
Glass.....	3300	0	0	0

\* Relative values are: CuO = 100, Ice = 70, Water = 0.25.

TABLE 4.—RELATIVE VALUES OF PHOTOELECTRIC CURRENT ( $I$ ) FOR HETEROCHROMATIC ILLUMINATION

The data given in different sections of the table are not comparable, as the relative intensities and spectral distributions are not known. Unit of  $I$  is arbitrary and varies from section to section.

Symbol	$I$	Symbol	$I$	Symbol	$I$
Hg-arc (5)					
Bi <sub>2</sub> O <sub>3</sub> .....	110	FeCl <sub>2</sub> .....	26	HgCl.....	12
Bi <sub>2</sub> O <sub>5</sub> .....	70	FeCl <sub>3</sub> .....	1	HgCl <sub>2</sub> .....	2
Cr <sub>2</sub> O <sub>3</sub> .....	50	FeO.....	7 200	HgI.....	112
CrO <sub>3</sub> .....	1	Fe <sub>2</sub> O <sub>3</sub> .....	202	HgI <sub>2</sub> .....	10
CuCl.....	50 000	Hg(C <sub>2</sub> H <sub>5</sub> -		Hg <sub>2</sub> O.....	280
CuCl <sub>2</sub> .....	10	CO <sub>2</sub> ).....	18	HgO.....	70
Cu <sub>2</sub> O.....	14 400	Hg(C <sub>2</sub> H <sub>5</sub> -		MnO.....	500
CuO.....	4 800	CO <sub>2</sub> ) <sub>2</sub> .....	12	Mn <sub>2</sub> O <sub>4</sub> .....	130



TABLE 4.—(Continued)

Symbol	I	Symbol	I	Symbol	I
Hg-arc (5)		Hg-arc (5)		Zn-spark (51)	
MnO <sub>2</sub> .....	48	KBr.....	320	MnS <sub>2</sub> .....	141
PbO.....	3 200	KCl.....	67	MoS.....	28
PbO <sub>2</sub> .....	1 700	KI.....	1 200	NiS.....	102
SnO.....	1 220	PbBr <sub>2</sub> .....	97	PbS.....	887
SnO <sub>2</sub> .....	24	PbCl <sub>2</sub> .....	31	Sb <sub>2</sub> S <sub>3</sub> .....	45
SnS.....	1 400	PbI <sub>2</sub> .....	3 000	SnS.....	236
SnS <sub>2</sub> .....	186	Zn-spark (51)		Zn.....	530*
AgBr.....	430	Ag <sub>2</sub> S.....	240	ZnS.....	80
AgCl.....	200	Al.....	200*	Hg-lamp (1)	
AgI.....	750	Bi <sub>2</sub> S <sub>3</sub> .....	128	Ag <sub>2</sub> S.....	2 150
CdBr <sub>2</sub> .....	21	CdS.....	58	Bi <sub>2</sub> S <sub>3</sub> .....	112
CdCl <sub>2</sub> .....	60	CoAsS.....	89	CdO.....	27
CdI <sub>2</sub> .....	18	CoS.....	29	CoS.....	820
HgBr.....	19	Cr <sub>2</sub> S <sub>3</sub> .....	160	CuO.....	295
HgBr <sub>2</sub> .....	14	Cu <sub>2</sub> S.....	534	CuS.....	490
HgCl.....	15	CuS.....	391	FeS.....	91
HgCl <sub>2</sub> .....	5	FeS.....	64	PbO <sub>2</sub> .....	15
HgI.....	1 400	FeS <sub>2</sub> .....	176	PbS.....	1 070
HgI <sub>2</sub> .....	230	Fe <sub>2</sub> S <sub>3</sub> .....	122	SnS.....	346
		MnS.....	385		

\* Assumed as a basis of reference.

TABLE 5.—RELATIVE PHOTOELECTRIC SENSITIVITIES OF AQUEOUS SOLUTIONS AND ALLOYS: VARIATION WITH CONCENTRATION (29)

Of the Pd-Ag alloys saturated with H, that of 40% Ag has maximum sensitivity and also maximum absorptive power for H (25). Nature of light source is unknown. Unit is so chosen that sensitivity of pure H<sub>2</sub>O = 1. Unit of concentration = 1%.

Concn.	NaCl	Na <sub>2</sub> SO <sub>4</sub>	NaNO <sub>3</sub>	Na <sub>2</sub> CO <sub>3</sub>	KCl	K <sub>2</sub> SO <sub>4</sub>
2	0.85	3.25			0.35	1.56
10	0.50	4.65	4.11	3.97	0.30	3.60
15	0.50	5.60			0.30	5.40

CRITICAL POTENTIALS OF ATOMS AND MOLECULES<sup>1</sup>

F. L. MOHLER

## CONTENTS

Symbols.....	PAGE 69
Useful relations.....	70
Critical potentials of atoms.....	70
Critical potentials of molecules.....	72

When the molecules of a gas are bombarded by electrons possessing kinetic energy ( $V_e$ ) the collisions are perfectly elastic unless  $V$  exceeds certain critical values  $V_c$ . At and above the velocities corresponding to these values  $V_c$ , an amount of energy  $eV_c$  can be lost in an inelastic collision, and this may be accompanied by the emission of radiation, or the energy may be dissipated in thermal agitation of the gas. If  $V$  equals or exceeds certain other critical values ( $V_i$ ), ions are produced, i.e., electrons are removed from the atomic structure. At every critical potential, the collisions are completely inelastic and the momentum given to the atom or molecule is negligible. Hence these values of  $V$  measure directly the energy expended in producing the resulting excitation or ionization. These critical potentials form the subject of this section.

From Bohr's quantum theory of radiation (Vol. I, p. 47, V, p. 392, 408, 409, 418 and VI, p. 23),  $eV_i = h \times$  (limiting frequency of an absorption series), and  $eV_c = h \times$  (frequency difference between the normal and another spectral term). The selection principles (Vol. V, p. 392 and VI, p. 23), which limit the combinations of terms that result in radiation, do not apply to excitation

<sup>1</sup> Covers data to Nov. 1, 1927.

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Aulenkamp, 96, 18: 70; 23. (2) Burt, 2, 23: 774; 24. (2.5) Cardwell, 197, 14: 439; 28. (3) Compton and Ross, 2, 13: 374; 19. (4) Dember, 8, 23: 957; 07. (5) Dima, 34, 156: 1366; 13. 157: 590; 13. (6) Elster and Geitel, 8, 48: 625; 93. 63, 14: 741; 13. (7) Elster and Geitel, 63, 17: 268; 16. (8) Elster and Geitel, 63, 21: 361; 20. (9) Farwig, 96, 21: 38; 24. (10) Goldmann and Kalandyk, 8, 36: 589; 11. (11) Hagenow, 2, 13: 415; 19. (12) von Halban and Ebert, 96, 14: 182; 23. (13) Hamer, 48, 9: 251; 24. (14) Hennings, 2, 4: 228; 14. (15) Hughes, 201, 15: 483; 10. (16) Hughes, 201, 16: 376; 11. (17) Hughes, 62, 312: 205; 12. (18) Hughes, 3, 24: 380; 12. (19) Hughes, 337, 2: 83; 21. (20) Ives, 48, 8: 551; 24. (21) Ives, 21, 60: 209; 24. (22) Kasda, 2, 22: 523; 23. (23) Kelly, 2, 16: 260; 20. (24) Koppius, 2, 18: 443; 21. (25) Krüger and Ehmer, 96, 14: 1; 23. (26) Küstner, 8, 46: 893; 15. (27) Kunz, 2, 13: 310; 19. (28) Kunz and Stebbins, 2, 7: 62; 16. (29) Kunz and Williams, 2, 22: 456; 23. (30) Ladenburg, 88, 9: 165; 07. (31) Lenard, 8, 8: 149; 02. (32) Lienhop, 8, 21: 281; 06. (33) Ludlam, 3, 23: 757; 12. (34) Millikan, 2, 7: 355; 16. (35) Millikan and Souder, 197, 2: 19; 16. (36) Millikan and Winchester, 3, 14: 188; 07. (37) Nieleen, 2, 22: 525; 23. (38) Nielsen, 2, 25: 30; 25. (39) Obolensky, 8, 39: 961; 12. (40) Palmer, 2, 32: 1; 11. (41) Partsch and Hallwachs, 8, 41: 247; 13. (42) Piersol, 2, 8: 238; 16. (43) Piersol, 2, 23: 144; 24. (44) Pohl and Pringsheim, 88, 12: 697; 10. (45) Pohl and Pringsheim, 88, 15: 111; 13. (46) Pohl and Pringsheim, 63, 14: 1112; 13. (47) Pohl and Pringsheim, 88, 16: 336; 14. (48) Richardson and Compton, 3, 24: 575; 12. (49) Richardson and Rogers, 3, 29: 618; 15. (50) Richtmyer, 2, 29: 71; 09. 30: 385; 10. (51) Rohde, 8, 19: 935; 06. (52) Seiler, 21, 52: 129; 20. (53) Sende and Simon, 8, 65: 697; 21. (54) Serkof, in Hughes, *Photo-Electricity*. Cambridge, Cambridge Univ. Press, 1914. (55) Shinomiya, 21, 49: 303; 19. (56) Souder, 2, 8: 310; 16. (57) Stark, 63, 10: 614; 09. (58) Steubing, 63, 10: 787; 09. (59) Stuhlman, 2, 13: 109; 19. (60) Stuhlman, 2, 15: 549; 20. (61) Tucker, 2, 22: 574; 23. (62) Varley and Unwin, 68, 27: 117; 07. (63) Volmer, 8, 40: 775; 13. (64) Welo, 3, 45: 593; 23. (65) Wiedmann and Hallwachs, 88, 16: 107; 14. (66) Williamson, 2, 21: 107; 23. (67) Young, 5, 104: 611; 23.

by collision, hence it is possible to produce states (called metastable) from which a radiating transition is impossible. A double excitation may result from a single collision if  $V$  is sufficiently great, and by increasing the current density of the electron stream, the same result may be obtained by successive collisions at a lower value of  $V$ .

In the case of atoms, the energy levels are determined solely by the electronic states, but in the case of molecules, a series of vibrational and rotational states is associated with each electronic state, and every change in electronic level is spontaneously accompanied by a change in vibration and rotation (3). Electrons probably can do directly no more than change the electronic state, and, if the spontaneous change in the state of vibration is small, the exciting potential will be nearly equivalent to the difference in the electronic energy levels. Such seems frequently to be the case, but there are many exceptions, and in some states the vibrational change is sufficient to cause spontaneous dissociation. The work of dissociation of a molecule into uncharged constituents is measured by the maximum vibrational energy that the molecule can have; i.e., by the frequency limit of a vibration series. General references (17, 33, 36, 57, 97).

## SYMBOLS

$e$ ,  $h$ , and  $\lambda$  have their usual significance (Vol. I, p. 16).  
 $D[D^+]$  Potential difference corresponding to work of dissociation of normal molecule (into uncharged atoms) [of molecule ion (into an uncharged and a charged atom)].



$i$	Current density of electron stream.
I	Ionization methods (17).
$I_M/I_A$	Ionization potential of the molecule [of the atom].
IC	Method of inelastic collision (17).
PR	Method of positive-ray analysis for identification of ions (17).
R	Methods involving photoelectric effect and electron emission produced by excited atoms (17, 76).
S	Method of critical potential required for appearance of a spectral line or group (17).
V	Potential difference required to produce the effect considered.
$V_o[V_d]$	Observed [computed] value of $V$ .
$V_I[V_{IC}]$	Value of $V$ which corresponds to ionization [derived by method IC].
X	Holweck's method (49).
$\approx$	Means "is equivalent to," or "corresponds to."
$(m_n)^*$	Indicates that there are $n$ electrons in the valence shell defined by the quantum numbers $m$ and $k$ (cf. Vol. I, p. 48).
$[m_k]$	Indicates that one electron is removed from a shell defined by $m$ and $k$ . If the normal atom contains $(3s)^{10}(4s)$ , then $[3s]$ indicates that the resulting ion contains $(3s)^9(4s)$ ; (cf. Cu, Table 1).

The quantum numbers and series notation used in this report are as follows: (For additional information, see Vol. I, p. 47, V, p. 392 and VI, p. 23.)

Alkali series*	$1^2S$	$2^2S$	$2^2P_1$	$2^2P_2$	$3^2S$
X-ray term†	$K$	$L_I$	$L_{II}$	$L_{III}$	$M_I$
Quantum number	1	2	2	2	3
Electrons‡	2	2	2	4	2

Alkali series*	$3^2P_1$	$3^2P_2$	$3^2D_2$	$3^2D_3$
X-ray term†	$M_{II}$	$M_{III}$	$M_{IV}$	$M_V$
Quantum number	3	3	3	3
Electrons‡	2	4	4	6

\* Russell's notation. † Coster's notation. ‡ Number of electrons in completed group.

**Useful Relations.**—The relation between critical potentials ( $V$ ) and wave number ( $\nu$  = waves per cm in vacuum) or wave-length in vacuum ( $\lambda_0$  expressed in Angstrom) is  $V = 1.2344\nu \times 10^{-4}$  volt =  $1.2344 \times 10^4/\lambda_0$  volt.

The relation between  $V$  for a reaction (ionization, dissociation) and the energy ( $E$ ) of the reaction is  $E/V = 2.307 \times 10^4$  (g-cal./mole per g-mole)/volt. For diatomic molecules of elementary substances  $D + I_A = I_M + D^+$ .

TABLE 1.—CRITICAL POTENTIALS OF ATOMS

In columns (1), (2), and (3) are symbol of the element and its atomic number, experimental method, and reference letter for following notes.  $\lambda_r$  = wave-length of resonance line of absorption spectrum. For other symbols, see above. Accuracy of  $V$  is roughly indicated by the number of significant figures. Unit of  $V_o$  and  $V_c$  = 1 volt; of  $\lambda_r$  = 1 Å =  $10^{-8}$  cm.

(1)	(2)	(3)	$V_o$	Lit.	$V_c^*$	Lit.	Transition	$\lambda_r$
Al18....	IC		11.5	(42)	11.57	(106)	$3^1S - 4^1P$	1066.7
	IC		13.0	(42)	11.77	(106)	$3^1S - 4^1P_2$	1048.2
	IC		13.9	(42)				
	I	a	15.4	(42)	13.69	(106)	$M_{III}[3_2]$	
	I	b	19.0	(20)	15.86	(106)	$M_{II}[3_2]$	
	R		32.2	(81)				
	R	c	34.8	(81)				
	R		39.6	(81)				
	X		246.5	(49)			$L_{III}[2_2]$	

Are spectrum at a, second spectrum at b if  $i$  is great, at c if  $i$  is small (20, 54). A third spectrum at 70 volt (20).

\* From (33, 97) unless another source is indicated.

TABLE 1.—(Continued)

(1)	(2)	(3)	$V_o$	Lit.	$V_c^*$	Lit.	Transition	$\lambda_r$
Ag47....	IC		3.1	(107)	3.65		$5^1S - 5^1P_2$	3383
					3.76		$5^1S - 5^1P_1$	3281
			6.0	(107)	7.54		$5^1S[5_1]$	
Al13....		a			5.96		$3^1P_1[3_2]$	
		b			10.0		$[3_1]$	
					18.17	(101)	$3^1S Al^+$	
					28.32	(96)	$3^1S Al^{++}$	
	X	c	68	(49)			$L_{III}[2_2]$	
b is from $a + 3^1S - 3^1P_1$ of $Al^+$ c measured by absorption of soft X-rays in solid Al.								
As33....	IC		4.7	(100)			$4^1S[4_1]$	
	I		11.5	(100)				
Au79					4.61	(116)	$6^1S - 6^1P_2$	2676
					5.08	(116)	$6^1S - 6^1P_1$	2428
					9.25	(116)	$6^1S[6_1]$	
B5		a			8.34	(78)	$2^1P_1[2_2]$	
		b			11.92	(9)	$[2_1]$	
					24.2	(78)	$2^1S B^+$	
					37.79	(78)	$2^1S B^{++}$	
		c	192	(49)	176	(18)	$K[1_1]$	
b is computed from $a +$ excitation potential of $(2^1S - 2^1P_1)$ of $B^+$ . c is computed from $K\alpha + a$ .								
Ba56....					1.56		$6^1S - 6^1P_1$	
					2.23		$6^1S - 6^1P$	
					5.19		$6^1S[6_1]$	
					9.96		$6^1S Ba^+$	
Ba $\rightarrow$ Ba $^{++}$ requires 15.15 volt								
Be4....					9.50	(78)	$2^1S[2_1]$	
					18.14	(78)	$2^1S Be^+$	
Be $\rightarrow$ Be $^{++}$ requires 27.6 volt								
Bi83....	IC	a	1.9	(100)	1.4			
					to			
					2.7			
	IC, 8	b	3.9	(100)	4.02			3068
	IC, 8	c	5.7	(100)	5.42			2277
					to			to
					5.98			2062
	I	d	8.0	(100)			$6^1S[6_1]$	
a gives metastable states. Resonance line and 4722 at b, group of lines at c, complete arc at d; second spectrum at 14 volt, third above 20 volt (100).								
C6....		a			11.3	(78)	$2^1P_2[2_1]$	
					24.29	(78)	$2^1P_1 C^+$	
					45.5	(78)	$2^1S C^{++}$	
					64.23	(78)	$2^1S C^{+++}$	
	X	b	280.5	(49)	282	(18)	$K[1_1]$	
b computed from $a + K\alpha$								
Ca20....	IC		1.90	(86)	1.89		$4^1S - 4^1P_1$	6573
	IC		2.85		2.92		$4^1S - 4^1P$	4227
	I		6.01		6.09		$4^1S[4_1]$	
					11.82		$4^1S Ca^+$	
					24.5	(77)	$M_{III}[3_2]$	
					24.9	(77)	$M_{II}[3_2]$	
Ca $\rightarrow$ Ca $^{++}$ requires 17.91 volt								
Cd46....	IC	a	3.95	(86)	3.78		$5^1S - 5^1P_1$	3261
	IC	b	5.35		5.39		$5^1S - 5^1P$	2289
	I	c	9.0		8.95		$5^1S[5_1]$	
		d			16.84	(105)	$5^1S Cd^+$	
Resonance lines at a and b, complete arc at c (72). Spectrum of Cd $^{++}$ is great, at d (99). Cd $\rightarrow$ Cd $^{++}$ requires 25.8 volt.								
Cl17....	X		203	(49)			$L_{III}[2_2]$	
Measured in HCl								
Co27....		a			8.25	(102)	$4^1P[4_1]$	
		b			16.8	(102)	$4^1P Co^+$	
Normal Co is $(3s)^7(4s)^2$ ; b gives $(3s)^7$ , but normal Co $^{+}$ is $(3s)^6$ , and the lowest ionization potential involves the double transition $(3s)^7(4s)^2 \rightarrow (3s)^6$ , requiring 7.81 volt. $(3s)^6 \rightarrow (3s)^7$ requires 17.2 volt (102).								
Cr24....		a			6.74	(14)	$1^1S[4_1]$	
		b			8.24	(65)	$1^1D[3_1]$	
		c			16.6	(102)	$4^1S Cr^+$	
Normal Cr is $(3s)^4(4s)^2$ ; a gives $(3s)^4$ , b gives $(3s)^3(4s)^1$ , c $(3s)^3 \rightarrow (3s)^4$ .								
Cs55....	IC	a	1.48	(32)	1.38		$6^1S - 6^1P_2$	8943
					1.45		$6^1S - 6^1P_1$	8521
	I	b	3.9	(32)	3.88		$6^1S[6_1]$	
	R	c	13.0	(81)				
	R		18.5	(81)				
	R, S	d	21.5	(81)				
	R		39.0	(81)				

Resonance lines at a,  $6S - 7P$  at 2.7 volt,  $6S - 8P$  and  $6P - 8S$  at 3.2 volt, complete arc b (93). Spectrum of Ca $^{+}$  at c if  $i$  is great, at d if  $i$  is small. Third spectrum at 55 volt if  $i$  is small (81).



TABLE 1.—(Continued)

(1)	(2)	(3)	$V_0$	Lit.	$V_0^*$	Lit.	Transition	$\lambda_r$
Cu29...	a	I	7.8	(107)	1.38	(108)	$4^2S - 3^2D$	
					3.77		$4^2S - 4^2P_2$	3274
					3.80		$4^2S - 4^2P_1$	3248
	b	c	7.8	(107)	7.69		$4^2S[4_1]$	
					10.44	(109)	$MV[3_1]$	
	d				20.5	(109)	$Cu^+ \rightarrow Cu^{++}$	

Normal Cu contains  $(3s)^2(4s)^2$ ; a gives  $(3s)^2(4s)^2$ ; d  $(3s)^2$ .  $Cu \rightarrow Cu^{++}$  requires 28.2 volt.

F9.....	a				16.9	(78)	$2^2P[2_2]$	
					32	(78)	$2^2P F^+$	
	X	b	684	(49)	689	(1)	$K[1_1]$	

b from  $K\alpha + a$

Fe26...	a				7.83	(102, 119)	$4^2D[4_1]$	
	b				16.5	(102)	$4^2D Fe^+$	

Normal Fe contains  $(3s)^2(4s)^2$ ; b gives  $(3s)^2$ .

Ga31...	IC		3.07	(58)	3.06		$4^2P_1 - 5^2S$	4033
	IC		4.22	(58)	4.29		$4^2P_1 - 4^2D$	2874
	I		5.80	(58)	5.97		$4^2P_1[4_2]$	
	I		13.2	(58)			$[4_1]$	
	I				30.59	(13)	$4^2S Ga^{++}$	

There is one IC value not related to known spectrum (58).

Ge32...					45.51	(13)	$4^2S Ge^{+++}$	
H1.....	R	a		†	10.15		$N(1 - \frac{1}{2^2})$	1216
	R			†	12.03		$N(1 - \frac{1}{3^2})$	1026
	R			†	12.69		$N(1 - \frac{1}{4^2})$	973
	R			†	13.00		$N(1 - \frac{1}{5^2})$	950
	R			†	13.16		$N(1 - \frac{1}{6^2})$	938
	R			†	13.26		$N(1 - \frac{1}{7^2})$	931
	R	b		†	13.54		$N[1_1]$	
	R			†				

Complete arc spectrum at b if i is small, at a if i is great (23).

He2....	R, IC	a	19.75	(34.5, 37)	19.73	(69)	$1^1S - 2^1S$	
	R, IC		20.55	(34.5, 37)	20.55	(69)	$1^1S - 2^1S$	800.5
	R, IC		21.2	(34.5, 37)	21.12	(69)	$1^1S - 2^1P$	584.4
	R, IC	b	22.9	(34.5, 37)	22.98	(69)	$1^1S - 3^1P$	537.1
	I	c	24.6	(34.5, 37)	24.48	(69)	$1^1S[1_1]$	
	I, S	d			54.16		$4N He^+$	
	I, S	e	78.8	(34.5, 37)	78.64		$He \rightarrow He^{++}$	

Arcs strike at a if i is great (16). Near b lines  $2P - 3S$ ,  $2P - 3D$ , and  $2S - 3P$ , both singlets and triplets, appear. Complete arc spectrum at c (43). Line 4686 of  $He^+$  excited at d if i is great and at e if i is small (19).

Hg80...	IC, R	a	4.68	(35)	4.66		$6^1S - 6^3P_0$	
	IC, R		4.90	(35)	4.86		$6^1S - 6^3P_1$	2537
	IC, R		5.47	(35)	5.43		$6^1S - 6^3P_2$	
	IC, R		6.73	(35)	6.67		$6^1S - 6^1P$	1850
	IC, R	b	7.73	(35)	7.69		$6^1S - 7^1S$	
	IC, R		8.64	(35)	8.58		$6^1S - 7^3P_1$	1436
	IC, R		8.86	(35)	8.79		$6^1S - 7^1P$	1403
	I	c	10.40	(47)	10.39		$6^1S[6_1]$	
	PR	d	19	(110)	18.97	(13)	$6^1S Hg^+$	

Other R values, not related to known spectrum, are found (35). Resonance line at a,  $6^3P - 7^1S$  and  $6^3P_1 - 7^1S$  near b, complete arc spectrum at c (43). Second spectrum near d, third spectrum at 24 volt, and fourth at 57 volt (28).

I53.....	I		8.0	(112)			$5^2P[5_1]$	
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Measured in thermally dissociated vapor

In49....	IC		0.30	(58)	0.27		$5^2P_1 - 5^2P_2$	
	IC		3.03	(58)	3.01		$5^2P_1 - 6^2S$	4102
	IC		4.07	(58)	4.06		$5^2P_1 - 5^2D$	3039
	I		6.3	(58)	5.76		$5^2P_1[5_2]$	
	I		14.1	(58)			$[5_1]$	
K19....	IC	a	1.55	(115)	1.60		$5^2S In^{++}$	
					1.61		$4^2S - 4^2P_2$	7699
	I	b	4.1	(115)	4.32		$4^2S - 4^2P_1$	7665
	R, I	c	19	(79)			$4^2S[4_1]$	
	R		23.8	(81)				
	R, S	d	31.8	(81)				
	R		48.0	(81)				

Resonance lines at a,  $4S - 5^2P$ , at 3.3 volt,  $4P - 4D$  and  $4P - 6S$  at 3.7, and  $4S - 6P$  at 3.9 volt; complete arc spectrum at b (81). Spectrum of  $K^+$  at c if i is great, at d if i is small (79).

\* From (23, 97) unless another source is indicated.

† Values observed in gas thermally dissociated differed from those computed by  $\pm 0.05$  volt and are entirely different from values for ordinary ( $H_2$ ) hydrogen (95).

TABLE 1.—(Continued)

(1)	(2)	(3)	$V_0$	Lit.	$V_0^*$	Lit.	Transition	$\lambda_r$
Kr36...	IC		9.9	(44)				
	IC		10.5	(44)				
	IC		11.5	(44)				
	IC		12.1	(44)				
	I	a	13.3	(44)			$NIII[4_1]$	
	I	b	15.5	(20)				
	I	c	28.2	(20)				

Arc spectrum at a, second spectrum at b with high pressure and at c with low, third spectrum at 59 volt (20).

Li3.....					1.84		$2^2S - 2^2P$	6708
	R	a			5.37		$2^2S[2_1]$	

Arc spectrum at a, 2934 at b (79)

Mg12...	IC	a	2.65	(86)	2.70		$3^1S - 3^1P_1$	4571
	IC	b	4.42	(86)	4.33		$3^1S - 3^1P$	2852
	I	c	7.75	(86)	7.61		$3^1S[3_1]$	
	S	d	15	(30)	14.97		$3^2S Mg^+$	
	R		46	(83)	45.8	(77)	$LIII[2_2]$	
					46.1	(77)	$LII[2_2]$	

Resonance lines at a and b; complete arc spectrum at c; spectrum of  $Mg^+$  at d if i is great (30). With i small,  $Mg^+$  lines  $3S - 3P$  at 12 volt,  $3P - 4S$  and  $3P - 3D$  at 16, and  $3D - 4F$  at 19 volt (98). These equal c + exciting potentials of  $Mg^+$ .  $Mg \rightarrow Mg^{++}$  requires 22.58 volt.

Mn25...		a			7.40	(15)	$4^2S[4_1]$	
		b			15.7	(40, 102)	$7^2S Mn^+$	

Normal Mn contains  $(3s)^2(4s)^2$ ; a gives  $(3s)^2(4s)^2$ ; b,  $(3s)^2$ .

Mo42...		a			7.35	(59)	$7^2S[5_1]$	
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Normal Mo contains  $(4s)^2(5s)^2$ ; a gives  $(4s)^2$ .

N7.....					14.48	(52)	$2^4S[2_2]$	
					29.56	(78)	$2^3P_0 N^+$	
					47.2	(78)	$2^3P_1 N^{++}$	

Na11...	X		397	(49)			$K[1_1]$	
	IC	a	2.19	(115)	2.09		$2^2S - 2^2P_2$	5896
							$2^2S - 2^2P_1$	5890
	I	b	5.13		5.12		$2^2S[3_1]$	
	R, I	c	$35 \pm 2$	(79)				
	S	d	$44 \pm 2$	(79)				

Resonance lines at a,  $3S - 4P$  at 4,  $3P - 5S$  at 4.4,  $3P - 4D$  at 4.6 volt, and complete arc spectrum at b (90); second spectrum at c if i is great, at d if i is small (79).

Ne10...	IC		16.65	(42)	16.60	(70)	$2^1S - 3^1P_1$	743.8
					16.77	(70)	$2^1S - 3^1P_2$	735.9
	IC	a	18.45	(42)	18.42	(70)		
	I	b	21.5	(42)	21.47	(70)	$LIII[2_2]$	
					21.57	(70)	$LII[2_2]$	
	R	c	(33.4)					
	R	d	48	(81)				
	R	e	54.9	(81)				

Paschen's lines  $1s - 2p$  excited near a and complete arc spectrum at b (43). Second spectrum between d and e if i is small (5, 5, 81).  $c = e - b$ .

Ni28...		a			8.65	(102, 109)	$3^2F[4_1]$	
		b			17.15	(102)	$4^2F Ni^+$	

Normal Ni is  $(3s)^2(4s)^2$ ; b gives  $(3s)^2$ , but normal  $Ni^+$  is  $(3s)^2$ , and the lowest ionizing potential involves the double transition  $(3s)^2(4s)^2 \rightarrow (3s)^2$ , requiring 7.64 volt.  $(3s)^2 \rightarrow (3s)^2$  requires 18.2 volt.

O8.....		a			13.56	(51)	$2^3P[2_2]$	
					35.0	(78)	$2^4S O^+$	
					54.8	(78)	$2^3P_0 O^{++}$	
					77.0	(78)	$2^3P O^{++}$	
	X	b	528	(49)	510	(18)	$K[1_1]$	

b from  $K\alpha + a$

P15....					19.82	(7)	$3^3P_0 P^+$	
					30.04	(9)	$3^3P_1 P^{++}$	
					64.74	(8)	$3^3S P^{+++}$	
Pb82...	R		126	(83)			$LIII[2_2]$	
	IC	a	1.26	(87)	0.96	(39)		
					2.6			
			7.9	(87)	7.38	(39)	$6^3P_0[6_2]$	
					43.7	(13)	$6^3S Pb^{+++}$	

a gives  $6^3P_{1,2}$ ,  $6^1D$ , and  $7^1S$

Pd46...		a			9.5	(66, 109)	$1^1S[4_3]$	
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Normal Pd contains  $(4s)^2$ , a gives  $(4s)^2$ .

Rb37...	IC	a	1.6	(32)	1.55		$5^2S - 5^2P_2$	7948
					1.58		$5^2S - 5^2P_1$	7800
	I	b	4.1	(32)	4.16		$5^2S[5_1]$	
	R, I	c	16.0	(79)				
	R	d	21.6	(79)				
	R		25.2	(79)				

Resonance lines at a, complete arc spectrum at b (92). Spectrum of  $Rb^+$  at c with i great, at d with i small (79).



TABLE 1.—(Continued)

(1)	(2)	(3)	$V_0$	Lit.	$V_0^*$	Lit.	Transition	$\lambda$
Si16....					10.31	(50)	$3^2P[3_2]$	
					47.08	(9)	$3^2P_1, 8^{++}$	
	X	a	163	(49)	87.68	(10)	$3^2S, 8^{++++}$	
							$LIII[2_2]$	
a measured in $H_2S$								
Sc21....		a			6.57	(102, 104)	$3^2D[4_1]$	
		b			12.80	(102, 104)	$3^2D, 8^{++}$	
					25.1	(38)	$3^2D, 8^{++}$	
Normal Sc has $(3s)(4s)^2$ ; a gives $(3s)(4s)$ , b gives $(3s)$ .								
Se34....	I		12.7	(118)			$4^2P[4_1]$	
Measured in vapor which was not purely monatomic								
Si14....					7.94	(72)	$3^2P_1[3_1]$	
					16.27	(34)	$3^2P_1, Si^+$	
					31.66	(34)	$3^2S, Si^{++}$	
	X	a	98	(49)	44.95	(34)	$3^2S, Si^{++}$	
							$LIII[2_2]$	
a measured in $SiH_4$								
Sn50....					7.30	(74)	$5^2P_1[5_1]$	
					14.5	(99)	$5^2P_1, Sn^+$	
					40.40	(13)	$5^2S, Sn^{++}$	
Sr38....					1.79		$5^2S - 5^2P_1$	6893
					2.68		$5^2S - 5^2P$	4607
					5.67		$5^2S[5_1]$	
					10.98		$5^2S, Sr^+$	
Sr $\rightarrow$ $Sr^{++}$ requires 16.65 volt								
Ti22....		a			6.80	(102)	$3^2F[4_1]$	
		b			13.60	(102)	$3^2F, Ti^+$	
					28	(102)	$3^2D, Ti^{++}$	
					43.1	(102)	$3^2D, Ti^{++}$	
Normal Ti has $(3s)(4s)^2$ ; b gives $(3s)$ .								
Ti81....	IC		0.9	(88)	0.96		$6^2P_1 - 6^2P_1$	
		a			3.27		$6^2P_1 - 7^2S$	3776
		b			4.47		$6^2P_1 - 6^2D$	2768
	I	c	6.04	(88)	6.08		$6^2P_1[6_1]$	
	R	d	12.0	(88)			[6 <sub>1</sub> ]	
					30.62	(13)	$6^2S, Ti^{++}$	
Resonance line and $(6^2P_1 - 7^2S)$ at a; resonance line and $(6^2P_1 - 6^2D)$ at b; complete arc spectrum at c. Second spectrum at d (88).								
V23....		a			7.04	(75, 102)	$4^2F[4_1]$	
		b			14.4	(102)	$4^2F, V^+$	
					68.70	(38)	$4^2D, V^{++++}$	
Normal V is $(3s)(4s)^2$ ; b gives $(3s)$ , but normal $V^+$ is $(3s)^2$ , and the lowest ionization potential involves the double transition $(3s)(4s)^2 \rightarrow (3s)^2$ , requiring 6.76 volt. $(3s)^2 \rightarrow (3s)$ requires 14.7 volt (102).								
Xe54....	IC		8.3	(44)				
	IC		9.9	(44)				
	IC		11.0	(44)				
	I	a	11.5	(44)				
	I	b	13.0	(20)				
	I	c	24.2	(20)				
Arc spectrum at a; second at b if pressure is high, at c if pressure is low; third spectrum at 51 volt (20).								
Yt39....					20.40	(10)	$3^2D, Yt^{++}$	
Zn30....	IC	a	4.18	(86)	4.01		$4^2S - 4^2P_1$	3076
	IC	b	5.65	(86)	5.77		$4^2S - 4^2P$	2139
	I	c	9.3	(86)	9.35		$4^2S[4_1]$	
					17.89	(105)	$4^2S, Zn^+$	
Resonance lines at a and b. $(4^2P - 5^2S)$ below c; complete arc spectrum at c (43). Zn $\rightarrow$ $Zn^{++}$ requires 27.2 volt.								
Zr40....					34.17	(10)	$3^2D, Zr^{++}$	

\* From (33, 37) unless another source is indicated.

TABLE 2.—CRITICAL POTENTIALS OF MOLECULES  
Unit of  $V$  and  $D = 1$  volt

	$V_I$	$V_{IC}$	Lit.		$V_I$	$V_{IC}$	Lit.
$Br_2^*$	12.8		(71)	$HCl^\dagger$	13.75		(61, 71)
$Cl_2^*$	13.2		(71)				
$H_2$ ....	See Tab. 3			$HBr^\dagger$	23.5		(80)
$I_2^\dagger$ ....	10.1	2.3	(84)	$HI^\dagger$ ....	12.75		(61, 71)
$N_2$ ....	See Tab. 3						
$O_2$ ....	See Tab. 3			$H_2S$ ....	10.4		(71)
$P_2$ ....	13.3	5.8	(82)	$NO$ ....	See Tab. 3		
$S_2$ ....	12.2	4.8	(82)	$NH_3$ ....	11.1		(71)
$H_2O$ ....	13.2		(71)	$CO$ ....	See Tab. 3		

TABLE 2.—(Continued)

Molecule	$V_I$	$V_{IC}$	Lit.
$CHCl_3$ , Chloroform.....	11.5	6.5	(6)
$HCN$ , Hydrocyanic acid.....	14.8		(61)
$CH_4$ , Methane.....	14.4		(88.1)
$C_2N_2$ , Cyanogen.....	16.3		(88.1)
$C_2H_2$ , Acetylene.....	12.3		(88.1)
$C_2H_4$ , Ethylene.....	11.5		(88.1)
$C_2H_6$ , Ethane.....	12.8		(88.1)
$C_4H_{10}O$ , Ethyl ether.....	13.6	6.6	(6)
$C_6H_6$ , Benzene.....	9.6	6.0	(6)
$C_7H_8$ , Toluene.....	8.5	6.2	(6)
$C_8H_{10}$ , Xylene.....	10.0	6.5	(6)
$HgCl_2$ , Mercuric chloride.....	12.1		(31)
$ZnCl_2$ , Zinc chloride.....	12.9		(31)

\* Assuming that the vibration series limits measure the work of dissociation into a normal and an excited atom, the excited state being  $^2P_1$  (117),  $D_{CH_3} = 2.47$ ,  $D_{Br_2} = 1.96$ ,  $D_{I_2} = 1.53$ ; thermochemical data give 2.47, 2.00, and 1.50, respectively (27, 64).

† Near  $V_{IC}$  visible band spectrum is excited; near  $V_I$ , the ultra-violet bands and first atomic line spectrum; at 21.0 volt, second line spectrum (24). For  $D$ , see preceding note.

‡ These values of  $V_I$  are almost exactly the computed values for dissociation of  $HR$  into  $H^+$  and  $R^-$ , but  $PR$  shows (2) that for  $HCl$  the primary product is  $HCl^+$ , and this is confirmed by data for production of negative ions in  $HCl$  (20).

TABLE 3.—CRITICAL POTENTIALS OF  $H_2$ ,  $N_2$ ,  $O_2$ ,  $NO$  AND  $CO$ 

		$V_0$	Lit.	$V_0$	Bands	Lit.
$H_2$ .....	IC, R	$10.8 \pm 0.3$		11.15	Dicke-Hopfield	(22)
	IC, R	$12.4 \pm 0.4$	(55, 63, 94)	12.2	Dicke-Hopfield	(22)
	I, PR	$15.9 \pm 0.15$		15.3	$H_2^+$	(2.1)
	I	29.4				
Questionable evidence for one or two intermediate values of $V_0$ . Near a continuous spectrum (55). Molecular line-spectrum in two stages, one just below b, one above b. Atomic lines below b (24). $PR$ indicates that at and above b only $H_2^+$ is produced directly, and that $H^+$ and $H_2^+$ arise from collisions of $H_2^+$ with $H_2$ (45, 111); but collisions of electrons with $H_2$ do directly produce $H$ (56) and atomic radiation (5). From vibration series of normal state (22, 120), $D = 4.36$ . Electron collisions cause dissociation at $V = 11.5$ . Dissociation by absorption of light occurs at a frequency $\approx V = 14.53$ ; if one atom is left in the first excited state, $V = 4.36 + 10.15$ (Table 1) = 14.51. $D^+ = D + I_A - I_M = 4.36 + 13.54 - 15.3 = 2.6$ volt.						
$N_2$ .....	IC, R, S	$8.12 \pm 0.1$		8.52	Birge-Hopfield	(114)
	S	b 9.5		9.47	First positive (b-a)	(3)
	S	c $13.0 \pm 1.0$		13.13	Second positive (c-b)	(3)
	S	d 15.0	(11, 26, 60, 82, 112)	14.93	Fourth positive (d-b)	(3)
	I, S, PR	$16.7 \pm 0.3$			$N_2^+$	(46)
	S	f 19.6		19.85	First negative (f-a)	(3)
	R	24.6				
	R	29.9				

Atomic lines are directly excited (42) near  $V = 32$ . From vibration series of a (4),  $D = a + 3.9 = 12.0$ . Assuming afterglow of active nitrogen is from excitation of  $N_2$  by recombining atoms (113),  $D = a + 3.4 = 11.5$ . From  $N_2^+$  spectrum,  $D^+ = 9.06$ , whence  $D = D^+ + I_M - I_A = 9.06 + 16.7(a) - 14.48$  (Table 1) = 11.3. Mean  $D = 11.6$  (4). Minimum potential to give  $N^+$  is  $I_M + D^+ = 25.8$ .  $PR$  indicates that only  $N_2^+$  is produced directly, but by collisions of  $N_2^+$  and  $N_2$ ,  $N^+$  is formed near theoretical voltage (46).

$O_2$ .....	IC	a	7.9		6.10	Schumann	(3)
	I, PR	b	12.8	(47, 71)	14.1	} $O^+$	(47)
	I, PR	c	15.8	(71, 82)			
	S	d	19.2	(68)	18.8	First negative (d-b)	(3)
	S, PR	e	19.8	(68)	20.6	$O^+$	(47)
	S		21.0	(68)		Schuster	(3)

Observations by I are discordant; may be two processes: Direct dissociation (c) giving ions in high vibrational state, and production of excited molecules (b) which, by molecular collisions, give ions in zero vibrational state. At (e), atom ions (47) and atomic lines are produced by direct collision (68),  $e = D + I_A$ . Vibration series gives accurately (4)  $D = 7.05$ ; dissociation by absorption occurs here with position of maximum of absorption  $\approx 8$  volt ( $\approx a$ ?). From spectral data,  $D^+ = 6.5$ , which may be too low;  $I_M = I_A + D - D^+ \approx 13.56 + 7.05 - 6.5 \approx 14.1$ .

$NO$ .....				5.44	Gamma	(2)
				5.60	Beta	(2)
	I	a	9.4	(71)	$NO^+$	(48)
	PR	b	21	(48)	$O^+$	
	PR	b	22	(48)	$N^+$	

From vibrational states of normal level (4),  $D = 7.9$ , from thermochemical data and  $D$  for  $O_2$  and  $N_2$ ,  $D = 8.3$ .  $a = D_{NO} + I_A$  for  $O$ ;  $b = D_{NO} + I_A$  for  $N$ .

\* Values of  $V_0$  are based on value of  $V_0$  at q.



TABLE 3.—(Continued)

			$V_e$	Lit.	$V_e$	Bands	Lit.
CO.....	IC	a	5.8	(85)	5.97	Cameron	(53)
	IC	b	8.0	(85)	7.27		
	R, S	c	10.15*	(25, 41)	7.99	Fourth positive	(53)
	S	d	10.7*	(25, 41)	10.34	Third positive (c-a)	(53)
	S	e	11.1	(25)	10.72	Ångström (d-a)	(53)
	I	f	14.2*	(25, 41)	11.34	(e-b)	
	S	g	16.8*	(25, 41)	16.7	Comet-tail (g-f)	(53)
	S	h	19.9*	(25, 41)	19.8	First negative (h-f)	(53)

Three other spectroscopic levels between e and f. From vibrational states of normal level (4),  $D = 11.2$ ; from heat of combustion and  $D$  for  $O_2$ ,  $D = 10.8$ ; mean  $D = 11.0$ . From vibrational states,  $D^* = 9.8$ . As  $I_A (= I_M + D^* - D) = 14.2(f) + 9.8 - 11.0 = 13.0$  is, within experimental error,  $= I_A$  of O ( $= 13.56$ , Table 1), the dissociation of  $CO^+$  probably gives C and  $O^+$ .

\* Mean error  $\pm 0.1$ .

## LITERATURE

(For a key to the periodicals see end of volume)

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## DIELECTRIC CONSTANT AND DIELECTRIC STRENGTH

## COMPLETE INDEX

Standard liquids.  
Solid industrial insulators, Vol. II, p. 310.  
Liquid industrial insulators, Vol. II, p. 305.  
Other industrial materials; see class of material; consult final index.

Elementary substances, pure inorganic compounds and air.

All other materials, including all single crystals.

High voltage corona.

## INDEX COMPLET

Liquides étalons  
Matières isolantes industriels solides, Vol. II, p. 310.  
Matières isolantes industrielles liquides, Vol. II, p. 305.  
Autres matières industrielles; voir classe des matières; consulter l'index finale.

Substances élémentaires, composés inorganiques purs et air.

Toutes les autres matières y compris tous les cristaux isolés.

Décharge en couronne.

## GESAMT INDEX VERZEICHNIS

Normalflüssigkeiten.  
Feste Isolatoren der Technik, Bd. II, S. 310.  
Flüssige Isolatoren der Technik, Bd. II, S. 305.  
Anderes technisches Material; siehe unter Natur des Materials; berücksichtige den Schlussindex.

Elementare Stoffe, reine anorganische Verbindungen und Luft.

Alle anderen Materialien einschliesslich der Einkristalle.

Hochspannungskorona.

## INDICE COMPLETO

Liquidi campioni. . . . . 81  
Isolatori solidi industriali, Vol. II, p. 310.  
Isolatori liquidi industriali, Vol. II, p. 305.  
Altri materiali industriali, consultare l'indice in fondo.

Elementi, composti puri inorganici, e aria. . . . . 74

Tutti gli altri materiali, inclusi tutti i cristalli singoli. . . . . 81  
Corona ad alto voltaggio. . . 107

## INTRODUCTION

The dielectric constant ( $\epsilon$ ) of a material is a measure of the ratio of the electric displacement ( $D$ ) to the electric field intensity ( $E$ ),  $D = \epsilon E/4\pi$ ; for a vacuum,  $\epsilon = 1$  cgs unit. The value of  $\epsilon$  may be determined from the measurements (1) of electrical capacities, (2) of mechanical forces between charged conductors, or (3) of the wave lengths of electrical waves. All three methods yield the same result, except in so far as the value of  $\epsilon$  varies with the frequency ( $\nu$ ) of  $E$ . If electrical waves experience absorption in the substance, the index of the absorption (v. Vol. I, p. 34) being  $k'$ ,

then  $\epsilon = (1 - k'^2)\lambda_0^2/\lambda^2$ , where  $\lambda_0[\lambda] =$  wave-length, for frequency  $\nu$ , in vacuum [in substance]; values of  $\epsilon$  so obtained are accompanied by the corresponding values of  $k'$ , if known; when  $k'$  is not given, it is believed to be too small to affect the value of  $\epsilon$  within the stated limits of accuracy.

For variation of  $\epsilon$  with  $E$ , v. p. 106; with magnetic field, v. p. 105; with illumination, v. p. 79.

The dielectric strength ( $S$ ) of a material is defined as the minimum value, in the material, of the electric field intensity ( $E$ ) at which a disruptive discharge occurs. In many cases it appears



doubtful if  $S$  is a constant, characteristic of the material, as it frequently appears to vary with the nature of the electrodes and with the distance between them. As the determination of the actual maximum value of  $E$  occurring in the field at the instant of discharge is difficult, the value of  $S$  is frequently merely indicated by stating the kind of electrodes, the minimum distance ( $l$ ) between their surfaces, and the difference in their potentials at the instant of discharge, if the difference is increasing slowly and continuously (D.C.). If the voltage is alternating (A.C.) either the effective ( $V_e$ ) or the maximum ( $V_m$ ) value of the alternating poten-

tial difference of the electrodes is stated. If the potential difference varies as  $\sin \omega t$ ,  $V_m = 1.414 V_e$ . Electrical oscillations in the circuit may introduce serious errors and injure connected apparatus, and should be prevented from reaching the terminals by the insertion, in series with each terminal, of a non-inductive resistance of at least one ohm per volt. The effect of surrounding objects in modifying the electrical field must be considered, and very definite specifications for the construction of the gap must be followed if accurate values for the potential difference corresponding to a given spark length are desired (cf. p. 79, 80).

## DIELECTRIC CONSTANT AND DIELECTRIC STRENGTH OF ELEMENTARY SUBSTANCES, PURE INORGANIC COMPOUNDS, AND AIR

H. L. CURTIS AND F. M. DEFANDORF

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Dielectric constant, Curtis:	Constante diélectrique, Curtis:	Dielektrizitätskonstante, Curtis:	Costante dielettrica, Curtis:	
Gases.	Gaz.	Gase.	Gas.....	74
Solids and liquids.	Solides et liquides.	Feste und flüssige Stoffe.	Solidi e liquidi.....	75
Air.	Air.	Luft.	Aria.....	77
Water, ice, and steam.	Eau, glace et vapeur.	Wasser, Eis und Dampf.	Acqua, ghiaccio e vapore	78
Effect of illumination.	Effet de l'éclairage.	Einfluss der Belichtung.	Effetto dell'illuminazione.....	79
Dielectric strength, Defandorf:	Cohésion diélectrique, Defandorf:	Dielektrische Festigkeit, Defandorf:	Rigidità dielettrica, Defandorf:	
Gases.	Gaz.	Gase.	Gas.....	79
Air: sphere-gap data.	Air: données relatives à une ouverture entre sphères.	Luft: Kugelfunkenstrecke.	Aria: valori con intervallo tra sfere.....	79
Air: needle-gap data.	Air: données relatives à une ouverture entre pointes.	Luft: Nadelfunkenstrecke.	Aria: valori con intervallo tra punte.....	80

**Symbols.**— $l$  = liquid,  $s$  = solid,  $t_R$  = room temperature,  $v.p.$  = vapor pressure of the saturated vapor at the temperature indicated.  $\epsilon$  = dielectric constant,  $\nu$  = frequency of field used in obtaining  $\epsilon$ . Such expressions as "(80 p 160)" and "(10° t 100°)" indicate that the accompanying coefficients apply so long as  $p$  [ $t$ ] lies between 80 and 160 [10° and 100°]; "25; 45" in the temperature column indicates that the same value was found at 25° as at 45°. Other symbols unexplained in Vol. I, p. 16, will be defined where used.

No data have been found for the dielectric strength of any solid or liquid included in this section.

TABLE 1.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF PURE INORGANIC GASES

$(\epsilon_t - 1) = (\epsilon_0 - 1)[1 + \alpha t(10)^{-3} + \beta t^2(10)^{-6}]$ ;  $\epsilon - 1 = (ap + bp^3)(10)^{-4} = 3cd_1[1 + cd_1(10)^{-3}](10)^{-4}$ , where  $d_1$  = specific gravity of the gas with reference to itself at 0°C and 1 atmosphere.  $\epsilon = 1 + 0.001\Delta$ ;  $\nu = A \times 10^3$ . Unit of  $\epsilon = 1$  cgse unit; of  $p = 1$  atmosphere; of  $\nu = 1$  cycle/sec; of  $t = 1^\circ\text{C}$ .

	$\Delta_{t,p}$	$t$	$p$	$A$	$n$	Lit.
A.....	0.56	0	1	1	6	(15)
Br.....	12.8	180	1	Radio		(14)
H.....	0.26	0	1	$\leq 2$	6	(5, 12, 49, 75, 96, 151)
	0.928	-185	1	Radio		(106)
	$c = 90, t = 24$ (80 p 160)					
	0		0	0	0	(93)
He.....	0.074	0	1	0	0	(68)
Hg.....	0.74	400	1	3	8	(10)
N.....	0.555	0	1	5; 8	5	(5, 49)
	0.606	0	1	2	6	(108)
	0.581	0	1	Radio		(151)
	0.79	-75	1	1	6	(153)
	1.90	-189	1	1	6	(153)

TABLE 1.—(Continued)

	$\Delta_{t,p}$	$t$	$p$	$A$	$n$	Lit.
O.....	0.507	0	1	5	5	(5)
	0.510	0	1	8	5	(49)
	0.547	0	1	2	6	(108)
	0.518	0	1	Radio		(151)
	$c = 173, t = 13.5$ (35 p 110)					
	0		0	0	0	(93)
H <sub>2</sub> O.....	See Table 4					
HCl.....	2.6	100	1	Audio		(5)
	7.6	-75	1	Radio		(151)
	4.60	0	1	Radio		(151)
	2.50	100	1	Radio		(151)
	1.62	200	1	Radio		(151)
	1.40	300	1	Radio		(151)
HBr.....	3.44	-50	1	Radio		(151)
	3.13	0	1	Radio		(151)
	2.62	100	1	Radio		(151)
	2.30	200	1	Radio		(151)
	2.12	300	1	Radio		(151)
HI.....	2.38	-25	1	Radio		(151)
	2.34	0	1	Radio		(151)
	2.20	100	1	Radio		(151)
	2.15	200	1	Radio		(151)
	2.16	300	1	Radio		(151)
	2.18	350	1	Radio		(151)
SO <sub>2</sub> .....	9.5	0	1	0	0	(75)
	9.0*	0	1	0	0	(135)
	9.3†	0	1	Audio		(5)
	9.5	0	1	1	6	(153)
	5.3	100	1	1	6	(153)
	3.9	175	1	1	6	(153)

\*  $\alpha = -4.7$  (10° t 60°) (135).

†  $\alpha = -6.3$ ,  $\beta = 18.7$  (10° t 100°) audio (5).



TABLE 1.—(Continued)

	$\Delta_{t,p}$	$t$	$p$	$A$	$n$	Lit.
H <sub>2</sub> S.....	4.0†	0	1	1	6	(15)
	$\epsilon = 2.0§$	10	v.p.	Audio		(38)
N <sub>2</sub> O.....	0.99	0	1	0	0	(12)
	1.16	0	1	0	0	(75)
	1.13	0	1	2	6	(108)
	10	15	10	0	0	(82)
	25	15	20	0	0	(82)
	46	15	30	0	0	(82)
	72	15	40	0	0	(82)
			mm	% NO <sub>2</sub>		
N <sub>2</sub> O <sub>4</sub> + NO <sub>2</sub> ..	2.3	42.5	747	31		(5)
	2.4	49.7	746	39		(5)
	1.4	63.1	747	55		(5)
	1.4	68.7	741	63		(5)
	1.0	90.5	741	84		(5)
	1.3	92.1	747	85		(5)
			$p$	$A$	$n$	
NH <sub>3</sub> .....	8.37¶	0	1	Audio		(5)
	9.2	-30	1	1	6	(153)
	7.2	0	1	1	6	(153)
	4.0	100	1	1	6	(153)
	2.7	185	1	1	6	(153)
CO.....	0.69§	0	1	0	0	(12, 15, 75)
	0.70	0	1	5	1	(104)
	2.63	-189	1	Radio		(106)
CO <sub>2</sub> .....	0.98**	0	1	≤2	6	(5, 12, 49, 75, 104, 108, 134, 135)
	0.98††	0	1	1	6	(153)
	1.41	-73	1	Radio		(106)
	50	0	v.p.	0	0	(135)
	$c = 332, t = 13.5$	(10 p 50)	0	0		(93)
	8	15	10	0	0	(82)
	19	15	20	0	0	(82)
	37	15	30	0	0	(82)
	62	15	40	0	0	(82)
	See also Fig. 2					
CS <sub>2</sub> .....	2.9	0	1	0	0	(75)
	3.2††	0	1	0	0	(5)
Air.....	See Table 3					

†  $\alpha = -5$  (0° to 100°). § See Fig. 1.¶  $\alpha = -7.75, \beta = 31$  (18° to 108°) audio (5).\*\*  $\alpha = (3.71 + 0.05p)$  (9° to 66°) (1 p 5) (134, 135).††  $\alpha = -4.3, \beta = 11$  (-75° to 200°) (153).‡  $\alpha = -3.7$  (85° to 130°) (5).TABLE 2.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF PURE INORGANIC SOLIDS AND LIQUIDS AND ITS VARIATION WITH TEMPERATURE ( $t$ ), PRESSURE ( $p$ ), AND FREQUENCY ( $\nu$ )For SiO<sub>2</sub>, v. p. 341; for single crystals, v. p. 98

From certain solids it is difficult, or even impossible, to prepare plates which are sufficiently homogeneous to be used for a direct determination of the dielectric constant ( $\epsilon$ ) of the material. In such case, it is customary to deduce  $\epsilon$  from the effective dielectric constant ( $\epsilon'$ ) of a dry plate formed by compressing the powdered substance, or from the effective constant ( $\epsilon_1$ ) of such a plate when saturated with a liquid (dielectric constant =  $\epsilon''$ ) which does not dissolve the powder. For such deduction, one or another of the following equations is generally used:

(1)  $(\epsilon - 1)/d = (\epsilon' - 1)/d'$ ; (2)  $(\epsilon - 1)/d(\epsilon + 2) = (\epsilon' - 1)/d' \times (\epsilon' + 2)$ ; (3)  $(\epsilon - 1)/d(\epsilon + n) = (\epsilon' - 1)/d'(\epsilon' + n)$ ; (4)  $(\epsilon -$

$\epsilon'')/d = (\epsilon_1 - \epsilon'')/d'$ . Here  $d$  = density of the substance,  $d'$  = density of the dry plate, and  $n$  is Wiener's number (152).

All liquids are under the pressure of saturated vapor unless contrary is indicated in first column. In column (2),  $l$  = liquid,  $s$  = solid,  $ls$  = intermediate between liquid and solid,  $P$  indicates  $\epsilon$  was deduced from effective constant of a plate of compressed powder, its subscript indicates equation used.

$$\epsilon_t = \epsilon_{t_0} + \alpha(t - t_0)(10)^{-3} + \beta(t - t_0)^2(10)^{-6}; \epsilon_p = \epsilon_0(1 + ap(10)^{-4} + bp^2(10)^{-8}); \nu = A \times 10^n$$

Unit of  $\epsilon$  = 1 cgse unit, of  $p$  = 1 atmosphere, of  $\nu$  = 1 cycle/sec of  $t = 1^\circ\text{C}$

Formula	(2)	$\epsilon_{t_0}$	$t_0$	$A$	$n$	Lit.
A-Table.—The A-Arrangement						
Br.....	$l$	3.2	23	1	8	(114)
	$l$	3.1	$t_R$	1	8	(117)
C (Diamond)....	$s$	16.5	$t_R$	Audio		(103)
	$s$	5.5	$t_R$	1	8	(117)
Cl.....	$l$	1.97*	0	0	0	(82)
	$l$	2.0†	0	Audio		(38)
	$l$	1.9	14	2	6	(26)
H ( $p = 1$ ).....	$l$	1.22‡	-253	1	5	(16)
( $p = 1$ ).....	$l$	1.225§	-253	6	5	(148)
	$l$	1.253	-259	1	5	(145)
	$s$	1.21¶	-259.9	6	5	(148)
	$s$	1.21	-259.1	1	5	(145)
He ( $p = 1$ ).....	$l$	1.048	-268.9	6	5	(148)
	$l$	1.058	-270.8	6	5	(146)
	$l$	1.056	-271.3	6	5	(146)
I.....	$s$	10	23	1	8	(114)
	$s$	4	$t_R$	1	8	(117)
O ( $p = 1$ ).....	$l$	1.465	-182	0	0	(63)
( $p = 1$ ).....	$l$	1.493	-182	0	0	(44)
	$l$	1.46	-182	1	5	(16)
	$l$	1.51**	-203	1	5	(16, 146)
P ( $p = 1$ ).....	$l$	3.85	20; 45	1	8	(115)
	$s$	4.1	20	1	8	(115)
(Yellow).....	$s$	3.6	$t_R$	1	8	(117)
S    ( $p = 1$ ).....	$l$	3.42	400	Audio		(103)
( $p = 1$ ).....	$ls$	3.98	115	Audio		(103)
	$s$	4.22††	$t_R$	Audio		(103)
	$s$	4.0	$t_R$	0	0	(53)
	$s$	4.01††	0	0	0	(118)
	$s$	4.38	$t_R$	0	0	(130)
	$s$	4.05††	$t_R$	-5.0	1	(41)
	$s$	3.80§§	$t_R$	5.0	1	(41)
	$s$	4.03	$t_R$	8.0	1	(130)
	$s$	4.03	$t_R$	9.3	1	(42)
	$s$	4.2	16	1	3	(46)
P <sub>2</sub>		4.7	17	1	6	(74)
	$s$	3.24¶¶	25	3.8	10	(79)
	$s$	4.03¶¶	25	5.0	10	(79)
	$s$	4.00¶¶	25	7.5	10	(79)
Se.....	$s$	6.13***	20	5.0	1	(138)
	$s$	7.44	$t_R$	Audio		(103)
	$s$	6.14***	20	2.4	7	(138)
	$s$	6.6	$t_R$	1	8	(117)

\*  $\alpha = -3.0$  (-70° to 10°) (82). ¶  $\alpha = 45$  ( $t_0$  to -259.1°) (148).†  $\alpha = -3.5$  (0° to 140°) (38).\*\*  $\alpha = -2.2$  ( $t_0$  to -183°) (16, 146).

‡ Freshly crystallized.

§  $\alpha = -3.2$  (-259° to  $t_0$ ) (148). ††  $\alpha = +1$ ; (-140° to 80°) (118).

|| Several months old.

||| Power factor for solid S = 0.03 % at 16°C,  $\nu = 10^3$  (46); = 0.6 % at  $t_R, \nu = 10^5$  (57).

¶¶ From deviation of waves by a prism.

\*\*\* Vitreous; in dark.



TABLE 2.—(Continued)

Formula	(2)	$\epsilon_{t_0}$	$t_0$	A	n	Lit.
<b>B-Table.—Standard Arrangement; v. Vol. III, p. viii</b>						
H <sub>2</sub> O.....	See Table 4					
HCl.....	l	4.60	27.7	4	8	(113)
	l	8.85	- 90	4	8	(113)
HBr.....	l	3.82	24.7	4	8	(113)
	l	6.29	- 80	4	8	(113)
HI.....	l	2.9	21.7	4	8	(113)
	l	2.88	- 50	4	8	(113)
	s	3.95	- 70	4	8	(110)
SO <sub>2</sub> .....	l	15.6*	0	Audio		(37)
(p = 1).....	l	13.8	15	2	8	(87)
	l	12.4	22	1	8	(114)
SO <sub>3</sub> .....	l	3.56	21	1	8	(114)
	s	3.64	19	1	8	(114)
H <sub>2</sub> S†.....	l	5.75†	10	Audio		(38)
H <sub>2</sub> SO <sub>4</sub> (p = 1).....	l	>84§	20	1	8	(140)
	s	3.8	-180	1.2	2	(28)
S <sub>2</sub> Cl <sub>2</sub> .....	l	4.8	22	1	8	(114)
SOCl <sub>2</sub> .....	l	9.05	22	1	8	(114)
SO <sub>2</sub> Cl <sub>2</sub> .....	l	9.15	22	1	8	(114)
(p = 1).....	l	8.5	22	1	8	(140)
N <sub>2</sub> O.....	l	1.607¶	0	0	0	(82)
(p = 1).....	l	1.933	- 90			(63)
N <sub>2</sub> O <sub>4</sub> .....	l	2.56	15	1	8	(118)
	s	2.6	- 40	1	8	(115)
NH <sub>3</sub> .....	l	14.9	24.5	4	8	(96)
	l	15.5	20.5	4	8	(96)
	l	16.2	14	2	6	(26)
(p = 1).....	l	22	- 34	4	8	(52)
	l	25.4	- 77	4	8	(96)
	s	4.01	- 90	4	8	(96)
HNO <sub>3</sub> .....	s	2.4	**	1.2	2	(28)
NH <sub>4</sub> Cl.....	P <sub>2</sub>	7.0	$t_R$	1	6	(72)
NH <sub>4</sub> Br.....	P <sub>2</sub>	7.1	$t_R$	1	6	(72)
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> .....	P <sub>2</sub>	3.3	17	1	6	(74)
PH <sub>3</sub> .....	l	2.71	- 25	4	8	(96)
	l	2.55	- 60	4	8	(96)
PCl <sub>3</sub> .....	l	3.72	18	1	8	(115)
	l	3.4	22	1	8	(114)
POCl <sub>3</sub> .....	l	14	22	1	8	(114)
PBr <sub>3</sub> .....	l	3.88	18	1	8	(115)
PI <sub>3</sub> .....	l	4.12	65	1	8	(115)
	s	3.66	20	1	8	(115)
AsH <sub>3</sub> .....	l	2.05	15	4	8	(116)
	l	2.74	- 50	4	8	(116)
AsCl <sub>3</sub> .....	l	12.35	21	1	8	(114)
(p = 1).....	l	12.8	20	1	8	(140)
	l	12.6	17	1	8	(115)
	s	3.6	- 50	1	8	(115)
AsBr <sub>3</sub> .....	l	8.83	35	1	8	(115)
(p = 1).....	l	9.3	35	1	8	(140)
	s	3.33	20	1	8	(115)
	s	3.4	20	1	8	(140)
AsI <sub>3</sub> .....	l	7.0	150	1	8	(115)
	s	5.4	18	1	8	(115)
SbH.....	l	2.58	- 50	4	8	(96)
	l	2.93	- 80	4	8	(96)
SbCl <sub>3</sub> .....	l	33.2	75	1	8	(114)
	s	5.34	18	1	8	(114)

\*  $\alpha = -78$  (0° to 150°) (37).

† See Fig. 1.

‡  $\alpha = -23$ ,  $\beta = -25$  ( $t_0$  to 80°) (35).§  $d = 1.85$  g/cm<sup>3</sup>.¶  $\alpha = -6.1$  (-6° to 14°) (82).||  $\alpha = +9$  (-185° to -120°).

\*\* -185° to -110°.

TABLE 2.—(Continued)

Formula	(2)	$\epsilon_{t_0}$	$t_0$	A	n	Lit.
SbCl <sub>5</sub> .....	l	3.78	21.5	1	8	(114)
SbBr <sub>3</sub> .....	l	20.9	100	1	8	(115)
	s	5.05	20	1	8	(115)
SbI <sub>3</sub> .....	l	13.9	175	1	8	(115)
	s	9.1	20	1	8	(115)
CO <sub>2</sub> *.....	l	1.585†	0	0	0	(82, 135)
CS <sub>2</sub> (p = 1).....	l	2.58	46	Audio		(54)
(p = 1).....	l	2.6	25	Audio		(54)
(p = 1).....	l	2.64	20	1.2	2	(27, 45)
(p = 1).....	l	2.647‡	20	8.5	5	(78)
(p = 1).....	l	2.638§	19	Audio		(95)
(p = 1).....	l	2.64	17	4	8	(31)
(p = 1).....	l	2.61	15	1.5	8	(59)
(p = 1).....	l	2.644	13	7	2	(139)
(p = 1).....	l	2.676¶	0	Audio		(125)
(p = 1).....	l	2.68**	0	5	5	(71)
(p = 1).....	l	2.638††	0	Radio		(105)
(p = 1).....	l	2.631‡‡	10	Radio		(55)
(p = 1).....	l	2.64	- 75	1.2	2	(27, 45)
(p = 1).....	ls	2.93	- 95	5	5	(71)
(p = 1).....	ls	2.87	-100	5	5	(71)
(p = 1).....	ls	2.83	-105	5	5	(71)
(p = 1).....	ls	2.81	-110	5	5	(71)
	s	2.78§§	-180	5	5	(71)
	s	2.24	-185	1.2	2	(27, 45)
SiO <sub>2</sub> .....	See p. 341					
SiCl <sub>4</sub> .....	l	2.4	16	1	8	(115)
SnCl <sub>4</sub> .....	l	3.2	22	1	8	(114)
PbO.....	P <sub>4</sub>	25.9	15	1	8	(131)
PbF <sub>2</sub> .....	P <sub>1</sub>	3.6	$t_R$	1	6	(81)
PbCl <sub>2</sub> .....	P <sub>1</sub>	4.2	$t_R$	1	6	(81)
	P <sub>2</sub>	6.0	17	1	6	(74)
PbBr <sub>2</sub> .....	P <sub>1</sub>	4.9	$t_R$	1	6	(81)
PbI <sub>2</sub> .....	P <sub>1</sub>	2.4	$t_R$	1	6	(81)
PbS.....	P <sub>4</sub>	17.9	15	1	8	(131)
PbSO <sub>4</sub> .....	P <sub>2</sub>	14.3	17	1	6	(74)
Pb(NO <sub>3</sub> ) <sub>2</sub> .....	P <sub>2</sub>	37.7	18	6.3	7	(7, 67)
Pb(CHO <sub>2</sub> ) <sub>2</sub> .....	P <sub>2</sub>	2.6	17	1	6	(74)
PbCO <sub>3</sub> .....	P <sub>4</sub>	18.6	15	1	8	(131)
TlCl.....	P <sub>2</sub>	46.9	$t_R$	1	6	(72)
TlBr.....	P <sub>2</sub>	53.8	$t_R$	1	6	(72)
Hg <sub>2</sub> Cl <sub>2</sub> .....	s	9.4	$t_R$	1	6	(72)
HgCl <sub>2</sub> .....	P <sub>2</sub>	3.2	17	1	6	(74)
Hg(CN) <sub>2</sub> .....	P <sub>2</sub>	4.8	17	1	6	(74)
CuO.....	P <sub>4</sub>	18.1	15	1	8	(131)
CuCl <sub>2</sub> ·2H <sub>2</sub> O.....	P <sub>2</sub>	7.6	20	6.3	7	(7, 67)
CuSO <sub>4</sub> .....	P <sub>2</sub>	10.3	18	6.3	7	(7, 67)
CuSO <sub>4</sub> ·5H <sub>2</sub> O.....	P <sub>2</sub>	7.8	18	6.3	7	(7, 67)
	P <sub>4</sub>	5.5	15	1	8	(131)
AgCl.....	s	11.2	$t_R$	1	6	(72)
AgBr.....	s	12.2	$t_R$	1	6	(72)
AgCN.....	P <sub>2</sub>	5.6	$t_R$	1	6	(72)
FeO.....	P <sub>4</sub>	14.2	15	1	8	(131)
FeF <sub>3</sub> ·3H <sub>2</sub> O.....	P <sub>2</sub>	7.3	20	6.3	7	(7, 67)
CrF <sub>3</sub> ·4H <sub>2</sub> O.....	P <sub>2</sub>	6.8	21	6.3	7	(7, 67)

\* See Fig. 2.

†  $\alpha = -3.9$  (-7.5° to 17.5°) (82);  $\alpha = -2.7$ ,  $\beta = -110$  (-5° to 30°) (135).‡  $\alpha = 0.723$ ,  $\beta = -0.722$  (1 p 3000) (78).§  $\alpha = 0.726$ ,  $\beta = -1.33$  (1 p 500) (95).||  $\alpha = 0.757$ ,  $\beta = -3.71$  (1 p 130) (139).¶  $\alpha = -2.61$ ,  $\beta = -1.24$  (20° to 180°) (125).\*\*  $\alpha = -2.8$  (-90° to 200°) (71).††  $\alpha = -2.6$  (-5° to 37°) (135).‡‡  $\alpha = -1.9$  (10° to 40°) (85).§§  $\alpha = +0.3$  (-186° to -110°) (71).



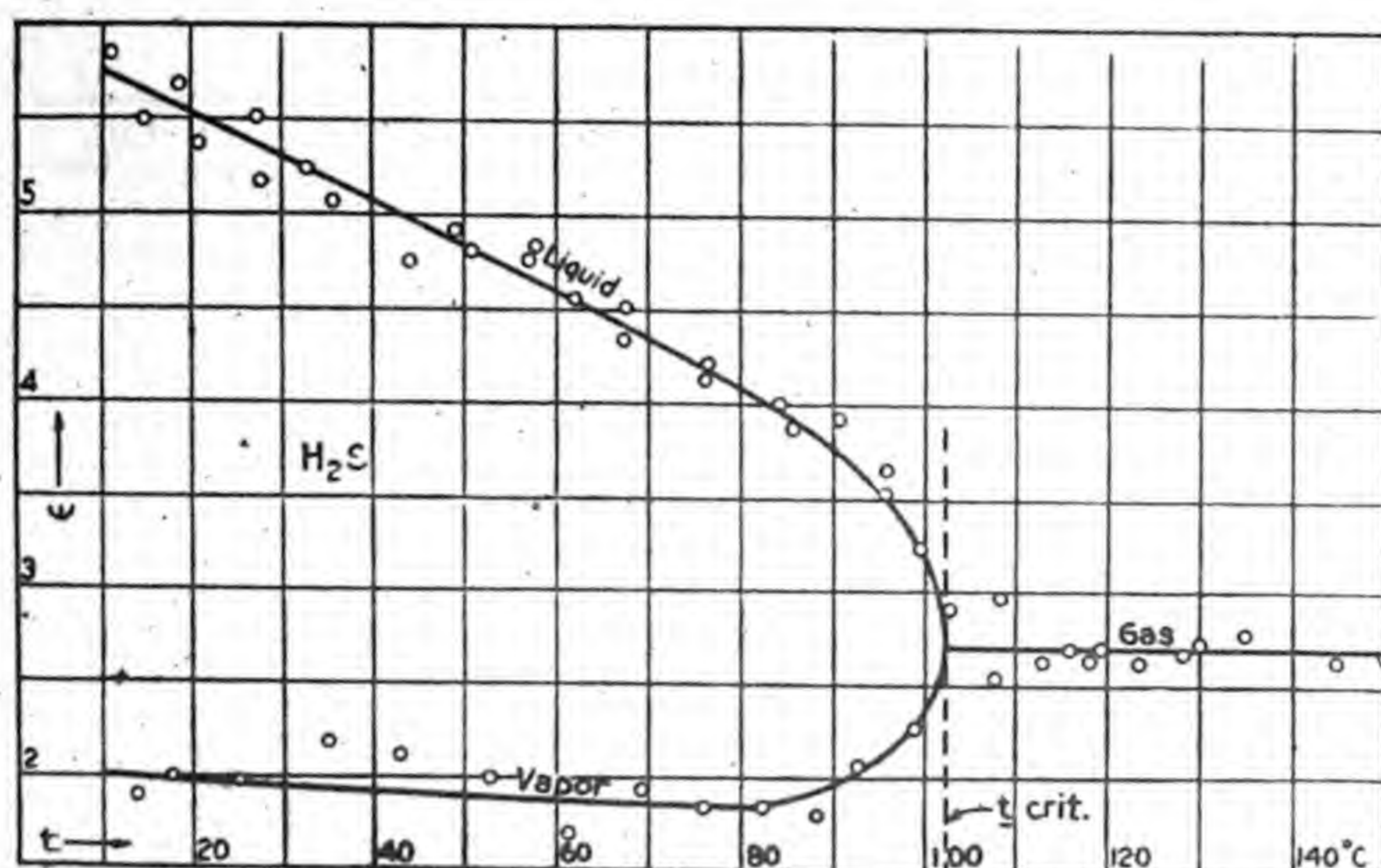


FIG. 1.—Dielectric constant ( $\epsilon$ ) of  $\text{H}_2\text{S}$  (<sup>28</sup>) at audio frequency. Below the critical temperature, pressure ( $p$ ) is that of the saturated vapor; above the critical temperature,  $p$  = critical pressure.

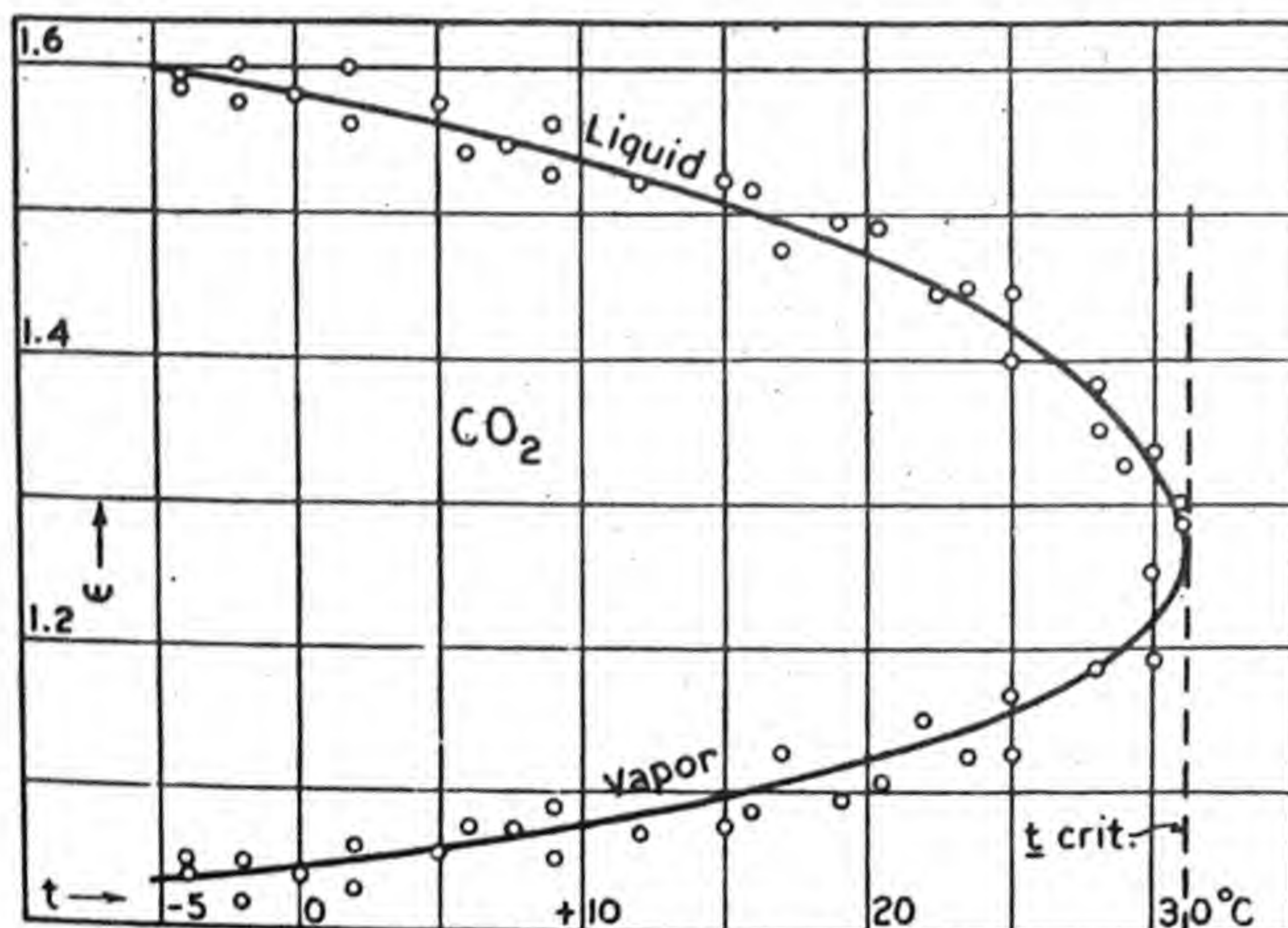


FIG. 2.—Dielectric constant ( $\epsilon$ ) of  $\text{CO}_2$  (<sup>135</sup>). Below the critical temperature, pressure ( $p$ ) is that of the saturated vapor; above the critical temperature,  $p$  = critical pressure;  $\nu = 4 \times 10^3$  cycle/sec.

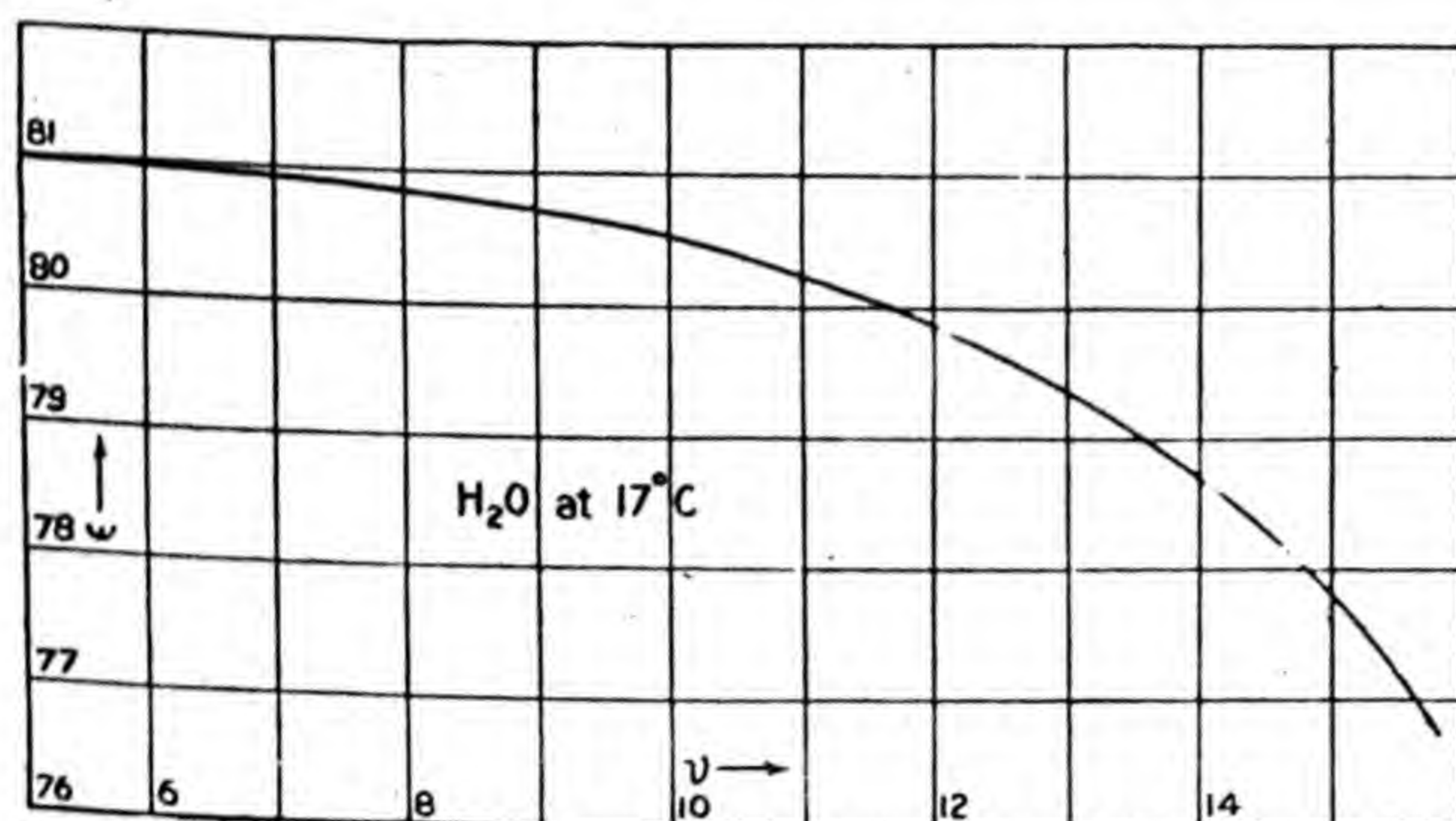


FIG. 3.—Dielectric constant ( $\epsilon$ ) of liquid  $\text{H}_2\text{O}$  at  $17^\circ\text{C}$ : Variation with frequency ( $\nu$ ) (<sup>25</sup>, <sup>26</sup>). Unit of  $\nu$  =  $10^3$  cycle/sec; of  $\epsilon$  = 1 cgs.

TABLE 2.—(Continued)

Formula	(2)	$\epsilon_{t_0}$	$t_0$	$A$	$n$	Lit.
$\text{CrO}_2\text{Cl}_2$ ( $p = 1$ )	$l$	2.6	20	1	8	(140)
$\text{VCl}_4$ .....	$l$	3.05	25	4	8	(84)
$\text{VOCl}_3$ .....	$l$	3.4*	0	4	8	(84)
$\text{VOBr}_3$ .....	$l$	3.85†	0	4	8	(84)
$\text{CaF}_2$ .....	$s$	7.36	$t_R$	Audio		(103)
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ....	$s$	5.61	15	1	6	(131)
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ....	$s$	5.66	$t_R$	Audio		(103)
$\text{CaCO}_3$ .....	$s$	6.14	$t_R$	1	6	(131)
$\text{BaF}_2$ .....	$P$	2.3‡	18	6.3	7	(7)
$\text{BaCl}_2$ .....	$P_3$	11.4	19	6.3	7	(7, 67)
$\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ ....	$P_3$	9.4	19	6.3	7	(7, 67)
$\text{BaBr}_2 \cdot 2\text{H}_2\text{O}$ ....	$P_3$	10.9	19	6.3	7	(7, 67)
$\text{Ba}(\text{BrO}_3)_2 \cdot \text{H}_2\text{O}$ ..	$P_3$	8.0	20	6.3	7	(7, 67)
$\text{Ba}(\text{IO}_3)_2 \cdot \text{H}_2\text{O}$ ..	$P_3$	12.9	18	6.3	7	(7, 67)
$\text{BaSO}_4$ .....	$P_4$	11.4	15	1	8	(131)
	$P$	3.3§	18	6.3	7	(7)
$\text{Ba}(\text{NO}_3)_2$ .....	$P_3$	5.9	18	6.3	7	(7, 67)
	$P_4$	9.15	15	1	8	(131)
$\text{Ba}(\text{CNS})_2 \cdot 3\text{H}_2\text{O}$ ..	$P_3$	12.8		6.3	7	(7, 67)
$\text{BaCrO}_4$ .....	$P$	4.25	18	6.3	7	(7)
$\text{NaF}$ .....	$P_3$	3.9	19	6.3	7	(7, 67)
$\text{NaCl}$ .....	$s$	6.12	$t_R$	Audio		(103)
	$s$	5.81	$t_R$	1	6	(131)
	$s$	9.3	$t_R$	4	9	(80)
	$P_3$	6.3	19	6.3	7	(7, 67)
$\text{NaClO}_4$ .....	$P_3$	5.4	19	6.3	7	(7, 67)
$\text{NaBrO}_3$ .....	$P_3$	7.7	19	6.3	7	(7, 67)
$\text{NaNO}_3$ .....	$s$	5.2	$t_R$	0	0	(4)
$\text{Na}_2\text{CO}_3$ .....	$P_3$	8.4	20	6.3	7	(7, 67)
$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ ...	$P_3$	5.3	20	6.3	7	(7, 67)
$\text{KF} \cdot 2\text{H}_2\text{O}$ .....	$P_3$	5.9	20	6.3	7	(7, 67)
$\text{KCl}$ .....	$s$	5.03	$t_R$	Audio		(103)
	$P_3$	4.9	19	6.3	7	(7, 67)
	$P_2$	2.4	17	1	6	(74)
$\text{KClO}_3$ .....	$P_3$	5.1	18	6.3	7	(7, 67)
	$P_4$	6.2	15	1	8	(131)
$\text{KBr}$ .....	$s$	4.6	$t_R$	1	6	(72)
	$P_3$	4.7	18	6.3	7	(7, 67)
$\text{KI}$ .....	$P_3$	5.6	18	6.3	7	(7, 67)
	$P_2$	5.2	$t_R$	1	6	(72)
$\text{K}_2\text{SO}_4$ .....	$P_3$	5.9	19	6.3	7	(7, 67)
	$P_4$	6.4	15	1	8	(131)
$\text{KNO}_3$ .....	$s$	2.7	$t_R$	0	0	(4)
	$P_3$	5.0	19	6.3	7	(7, 67)
$\text{K}_2\text{CO}_3$ .....	$P_4$	5.6	15	1	8	(131)
$\text{K}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$ ....	$P_3$	6.6	20	6.3	7	(7, 67)
$\text{K}_2\text{CrO}_4$ .....	$P_3$	7.3	19	6.3	7	(7, 67)
$\text{K}_2\text{Al}_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$ ....	$P_2$	3.8	17	1	6	(74)

\*  $\alpha = -0.4$  ( $-70^\circ$  to  $26^\circ$ ) (<sup>84</sup>).

†  $\alpha = -8$  ( $-70^\circ$  to  $30^\circ$ ) (<sup>84</sup>).

‡ For plate,  $d' = 1.6$  g/cm<sup>3</sup>, value not reduced.

§ For plate,  $d' = 1.9$  g/cm<sup>3</sup>, value not reduced.

|| For plate,  $d' = 1.85$  g/cm<sup>3</sup>, value not reduced.

TABLE 3.—DIELECTRIC CONSTANT OF AIR

For gaseous air,  $\epsilon = \frac{1 + 2c_1d_1}{1 - c_1d_1} = 1 + 3c_1d_1 + 3c_1^2d_1^2 + \dots = 1 + 3c_1d_1(1 + c_1d_1) + \dots$ ;  $d_1 = p/(1 + 0.003665t)$  if unit of  $p = 1$  atmosphere, of  $t = 1^\circ\text{C}$ .  $\epsilon$  is independent of frequency. If we write  $c_1 = c \times 10^{-6}$ ,  $c = 195$ ; tested and found



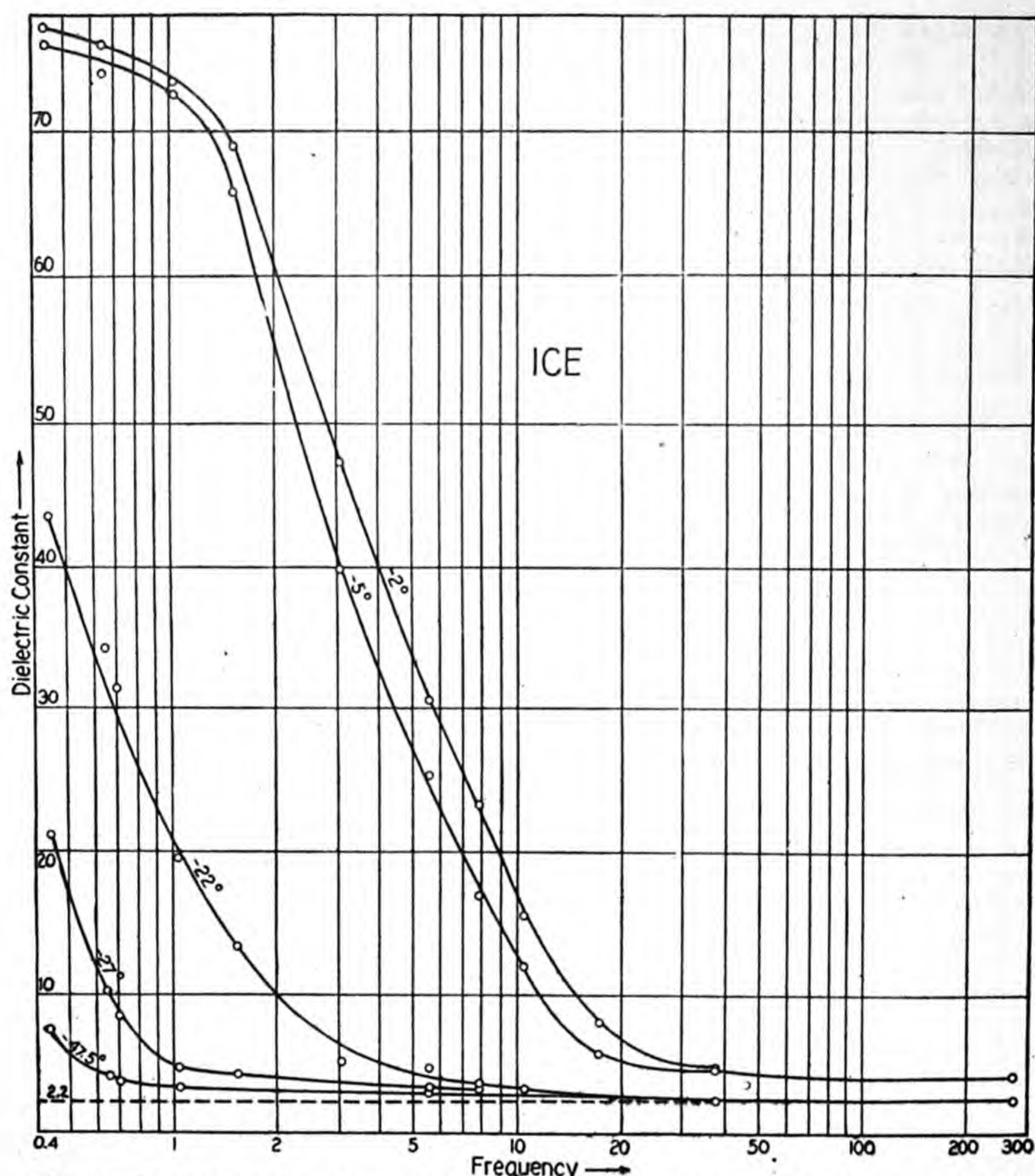


FIG. 4.—Dielectric constant ( $\epsilon$ ) of ice: Variation with frequency ( $\nu$ ) and temperature ( $t$ ) (<sup>36</sup>).  
Unit of  $\nu = 1$  kilocycle/sec; of  $\epsilon = 1$  cgse;  $t = ^\circ\text{C}$ .

constant for ( $0 \leq p \leq 175$ ); ( $0^\circ \leq t \leq 70^\circ$ ) (9, 19, 49, 51, 75, 92, 94, 104, 126, 127, 135, 139); at very low temperatures,  $c$  is a few per cent greater than 195; at  $-185.5^\circ\text{C}$ ,  $\epsilon - 1 = 0.001890/p$ .  $\nu$  = frequency, cycle/sec. Unit of  $\epsilon = 1$  cgse; of  $p = 1$  atm.; of  $t = 1^\circ\text{C}$ .

Gaseous, $p = 1$			Liquid, $p = 1$			
$t$	$\epsilon$	Lit.	$t$	$\epsilon$	$\nu$	Lit.
0	1.000585		-185	1.432	(?)	(103)
-185.5	1.00189	(106)	-185	2.28	$7.5 \times 10^9$	(88)

TABLE 4.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF  $\text{H}_2\text{O}$ ; STEAM, WATER, AND ICE

Unit of  $\epsilon = 1$  cgse unit, of  $p = 1$  atmosphere, of  $\nu = 1$  cycle/sec; of  $t = 1^\circ\text{C}$ .

Steam,  $p = 1$ , ( $140^\circ \leq t \leq 150^\circ$ ):  $\epsilon = 1.00785 - 0.00016(t - 140)$  (<sup>5</sup>). If ( $0 \leq p \leq 40$ ) ( $40^\circ \leq t \leq 165^\circ$ ),  $\epsilon = 1 + [9.3 - 0.026(t - 40)]p \times 10^{-4}$ , where unit of  $p' = 1$  mm of Hg (<sup>152</sup>).

Water,  $p = 1$ , ( $0^\circ \leq t \leq 100^\circ$ ) ( $0 \leq \nu \leq 10^8$ ):  $\epsilon = 80 - 0.4(t - 20)$ , (18, 23, 24, 28, 50, 65, 69, 73, 74, 86, 90, 91, 105, 107, 109, 110, 121, 122, 128, 131, 133, 150). For  $\nu > 10^8$ , the value of  $\epsilon$  is uncertain; two observers (25, 111), using standing waves along wires, find

$\epsilon$  decreases as  $\nu$  increases (see Fig. 3); another (<sup>79</sup>), from measurements of refraction, concludes that the reverse is true.

At  $16.8^\circ\text{C}$ ,  $\nu = 6 \times 10^7$  (7 p 200),  $\epsilon = 81.5 + 0.0046p$  (<sup>39</sup>).

Ice, at  $-5^\circ\text{C}$  ( $10^7 \leq \nu \leq 10^9$ ),  $\epsilon = -0.08 + 0.34 \log_{10} \nu$  (<sup>58</sup>). For variation with  $\nu$  and  $t$ , see Fig. 4. Other determinations are tabulated below.

$t$	$\epsilon_{t,\nu}$	$t$	$\epsilon_{t,\nu}$	$t$	$\epsilon_{t,\nu}$
$\nu = 50$ ( <sup>129</sup> )		$\nu = 120^*$ ( <sup>27, 45</sup> )		$\nu = 320$ ( <sup>28</sup> )	
-2	94	-80	31.5	-7	51
-10	95.2	-90	20.2	-47	3.6
-18	96.5	-100	14.5	Audio ( <sup>1</sup> )	
-182	3	-110	8.6	-80	3.8
$\nu = 120^*$ ( <sup>27, 45</sup> )		-120	6.1	$\nu = 5 \times 10^6$ ( <sup>2</sup> )	
-20	59.5	-130	4.7	0 to -24	3.8
-30	59.0	-140	3.5	$\nu = 10^7$ ( <sup>131</sup> )	
-40	58.5	-150	2.7	-2	3.4
-50	56.0	-165	2.43	-5	2.3†
-60	49.5	-185	2.43	-5	2.8
-70	41.5	-185	2.83	$\nu = 10^8$ ( <sup>11</sup> )	
				-190	1.8

\* Condenser charged and discharged by commutator, 120 charges per sec; see also Fig. 5. † From (<sup>58</sup>).



TABLE 5.—EFFECT OF ILLUMINATION UPON DIELECTRIC CONSTANT (56)

For a phosphorescent ZnS containing a trace of Cu,  $\epsilon_l - \epsilon_d = B e^{J/\lambda}$ , where  $\epsilon_l, \epsilon_d$  = dielectric constant in the light, in the dark, and  $J$  = irradiation of the material.  $B$  and  $\lambda$  vary with the wave-length ( $\lambda$ ) of the light. For room temperature and  $\nu = 3 \times 10^6$  cycle/sec, the following values were found. Unit of  $\lambda = 1 \mu = 10^{-6}$  m; of  $J = 10^{-12}$  watt  $\text{cm}^{-2}$ .

$\lambda$	313	365	405	435
$B$	0.006	0.035	0.042	0.033
$a$	13.2	9.1	5.0	12.4

TABLE 6.—RELATIVE DIELECTRIC STRENGTHS OF PURE INORGANIC GASES AT 25°C AND 1 ATMOSPHERE (6, 13, 64, 70, 76, 85, 97, 120, 132, 147, 149)

For other pressures,  $v$ . (61, 62, 97, 141, 147) or use Paschen's law ( $v$ . Table 7). Values are not affected by the electrode material except in the case of gases of low ionization potential at low pressure, but are affected by the condition of the electrode surface (32, 154). For a mixture of two gases which do not react chemically (64, 70)  $(p_1 + p_2)V = p_1V_1 + p_2V_2$  where  $p_1$  and  $p_2$  are the partial pressures of the two constituents of the mixture, and  $V_1$  and  $V_2$  are the sparking potentials for the pure constituents at 25°C and 1 atmosphere.

The presence of an ionizing radiation does not appreciably lower the electric strength of a gas, but makes the individual observations more concordant by eliminating the variable, temporary excess in voltage, which otherwise occurs (64, 89, 141, 158). For bibliography and discussion of data pertaining to the electrical breakdown of gases, see (120, 156).

$V/V_a$  = potential difference at which spark passes in gas divided by potential difference at which spark passes in air, the temperature (25°C), pressure (= 1 atm), terminals, and gap-length being the same for each. Accuracy, ca. 10%.

Gas	Cl	H	N	O	SO <sub>2</sub>	H <sub>2</sub> S	NH <sub>3</sub>	CO <sub>2</sub>
$V/V_a$	0.85	0.65	1.15	0.85	0.30	0.90	1.00	0.95

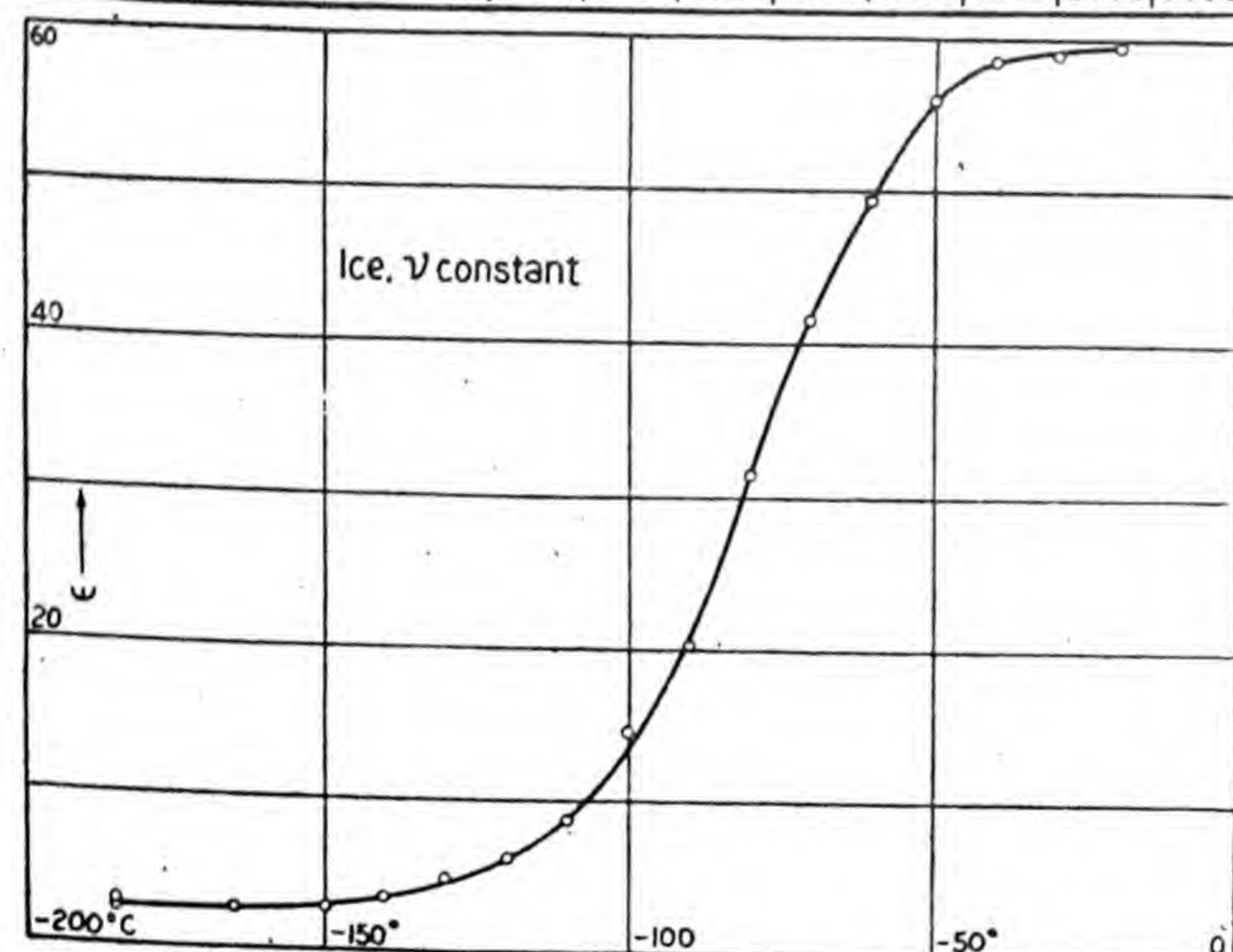
FIG. 5.—Dielectric constant ( $\epsilon$ ) of ice: Variation with temperature,  $\nu$  is constant at 120 charges (and discharges) per second (27, 45).

TABLE 7.—DIELECTRIC STRENGTH OF AIR: SPHERICAL ELECTRODES, 25°C AND 1 ATMOSPHERE

The tabulated data apply to gaps having the following characteristics: The electrodes are two spheres of the same diameter; variations in diameter should not exceed 0.1% and the curvature should nowhere differ from that of a true sphere by more than 1%. The spheres must be highly polished if the frequency of the emf is very high (e.g., 40 000 cycle per sec); at commercial frequencies

and for D.C. potential the degree of polish is much less important. Considerable deviation in successive breakdown values may occur if the sparking surfaces are not properly cleaned (154, 158). The diameter of the shanks supporting the spheres should not exceed 0.2 the diameter of the spheres, and if they pass through metal collars, the collars should be small and not closer to the gap than the length ( $l$ ) of the latter. Each sphere should be at least  $2l$  distant from all surrounding materials other than air.

For other temperatures and pressures, multiply the tabular values of  $V$  by the factor  $f$  (or, less accurately, by  $c$ );  $c = 298p/(273 + t)A_n$ ,  $f = \sqrt{c(\sqrt{cr + \delta})/\sqrt{r + \delta}}$ , where  $r$  = radius of the electrode,  $\delta = 0.54$  cm,  $p$  = pressure,  $A_n$  = pressure of one normal atmosphere. Paschen's law (147),  $V$  is a function of ( $dl$ ), holds throughout the range within which air is essentially an ideal gas (61); cf. (20, 21, 35, 60, 64, 141). Values of  $V$  are independent of the humidity of the air and of the electrode material (32, 98, 99, 124, 144),  $d$  = density,  $D$  = diameter of spheres,  $G$  = one sphere grounded, connected to earth,  $I$  = both spheres insulated from earth,  $l$  = shortest distance between surfaces of spheres,  $u$  = greatest uncertainty in the data, it is probably several times greater than actual error,  $V_m$  = maximum value of A.C. voltage. Unit of  $D$  and of  $l$  = 1 cm; of  $V_m$  = 1 kilovolt =  $10^{11}$  cgsm unit = 3.335 cgse unit.

$D$	0.25	0.50	1.0	$D$	2.0	2.5	3.0	4.0
$l$	$V_m$			$l$	$V_m$			
0.01	1.08	1.01	0.86	0.10	4.62		4.50	
.02	1.59	1.51	1.49	.20	7.84		7.80	8.4
.03	2.06	2.00	1.94	.30	10.9		11.0	11.4
.05	2.92	2.83	2.78	.40	13.9		13.8	14.4
.08	4.00	3.92	3.92	.50	16.9	18.3		17.4
.10	4.73	4.67	4.67	.60	19.7	21.4		20.2
.15	6.60	6.54	6.42	.80	24.9	27.2		25.4
.20	8.34	8.26	8.08	1.0	29.5	32.8		30.0
.30	11.3	11.4	11.3	1.2	33.4	38.3	37.8	34.2
.40	13.7	14.5	14.4	1.4	36.8	43.3	43.5	
.50	15.8	17.3	17.4	1.6	39.7	48.3	49.0	
.60	17.4	19.8	20.4	1.8	41.8	53.1	54.0	
.80	19.2	23.9	25.7	2.0	43.6	57.4	58.8	
1.00	20.5	26.9	29.8	2.5	45.8	66.5	69.3	
1.20	21.7		34.7	3.0	46.5	72.9	78.0	
1.40	22.5		38.3	3.5	48.3	78.0	84.7	
1.60			41.5	4.0	49.2	82.4	90.4	
				4.5	50.0	86.0	92.7	
				5.0	50.5	89.5		
				6.0	51.2			
				8.0	52.4			
$u$	5%	5%	5%	$u$	5%	7%	7%	10%
Lit.	(66, 97)	(66, 97)	(48, 66, 97, 137)	Lit.	(48, 77, 89, 137, 156)	(66, 97)	(6)	(48)

$D$	5.0	10.0	12.5	15.0	20.0
$l$	$V$				
	$I$	$G$	$I$	$G$	$G$
0.1			4.46	4.46	
0.2			7.64	7.64	
0.3			10.6	10.6	
0.4			13.4	13.4	
0.5	17.1	17.1	16.3	16.3	10.8
0.6	20.2	20.2	19.5	19.1	17.0
0.8	26.3	26.2	25.2	24.6	19.9
1.0	32.0	31.8	30.8	29.8	25.5
1.2	37.6	37.2	36.4	35.1	31.1
1.4	42.8	42.3	41.7	40.2	36.5
1.6	47.9	47.0	47.0	45.3	41.9
1.8	52.8	51.7	52.6	50.2	47.2
2.0	57.4	55.8	57.6		52.6
2.5	68.3	65.0	70.0		58.0
3.0	77.7	72.0	80.9		70.7
3.5	86.1	77.4	93.4		83.1
4.0	93.4	81.0	104.5		95.2
4.5	100.6	84.2	114.7		106.8
5.0	106.0	86.5	125.0		117.8
6.0	116.4	88.8	143.5		128.5
7.0	126.0	90.0	159.5		147.2
8.0	134	90.4	173.4		167
					184
					171



TABLE 7.—(Continued)

D	5.0	10.0	12.5	15.0	20.0
l	V				
	I	G	I	G	I
9.0	140	90.9	186		200
10.0	145	92	198		213
12.0	155	93	218		238
14.0	162		235		258
16.0	168		248		274
18.0	175		261		288
20.0	180		270		302
25.0	194		288		246
30.0	207		294		
35.0	220				
40.0	233				
45.0	248				
Lit.	(3, 66, 83, 89, 136, 137, 156)		(77, 136, 156)	(99, 101)	(77, 156)

D	25	30	50	75
l	V <sub>m</sub>			
	I	G	I	G
0.1			4.36	4.36
0.2			7.58	7.58
0.3			10.53	10.53
0.4			13.44	13.44
0.5			16.30	16.30
0.6			19.37	19.08
0.8			25.1	24.4
1.0		30.9	30.6	29.6
1.2			35.9	34.8
1.4		42.7	40.9	39.8
1.6			46.1	
1.8			51.1	
2.0		59.6	56.4	56.6
2.5		73.5	69.2	
3.0		86.7	82.2	84.0
3.5		99.4	95.2	
4.0	112.0	111.5	108.0	110.8
4.5	124.1	123.7	120.6	
5.0	136.0	135.0	133.0	137.0
6.0	160.8	159.6	157.8	162.6
7.0	181	178	181	188
8.0	202	198	205	212
9.0	222	218	227	236
10.0	241	235	247	259
12.0	277	268	284	305
14.0	310	296		347
16.0	341	320		387
18.0	369	342		425
20.0	392	360		456
25.0	443	392		502
30.0	480	417		605
35.0	514	441		696
40.0	548	460		784
45.0				866
50.0				936
60.0				1000
70.0				1120
80.0				1225
90.0				1303
Lit.	u = 5% except for D = 75.0, for which 7% (22, 99, 101, 156)			
		(156)	(22, 99, 101, 156)	(102)

TABLE 8.—DIELECTRIC STRENGTH OF AIR: NEEDLE ELECTRODES, 25°C AND 1 ATMOSPHERE (48, 99, 100, 101, 102, 136, 141, 157)

The tabular data apply to gaps having the following characteristics: The electrodes are new sewing needles, No. 00, supported axially at the ends of linear conductors at least 2*l* long. There must be no other material than air nearer than 2*l* to any portion of the gap. Needles must be replaced after each spark. A needle-gap is not suitable for the measurement of impulsive or high frequency voltage.

For other temperatures and pressures, multiply the tabular values of *V* by the factor *f* (or *c*), *v*. introduction to Table 7. Values of *V* vary with humidity, and for D.C. differ from *V<sub>m</sub>* of A.C., *h* = relative humidity, *u* = greatest uncertainty in the

data, it is probably several times greater than actual error, *V<sub>e</sub>* = effective A.C. voltage. Unit of *l* = 1 cm; of *h* = 1%; of *V*, *V<sub>m</sub>*, *V<sub>e</sub>* = 1 kilovolt = 10<sup>11</sup> cgs unit = 3.335 cgs unit.

<i>h</i>	0	57	70	75	82.5	<i>l</i>	A.C.	D.C.
<i>l</i>	<i>u</i> = 5%, <i>V<sub>e</sub></i> (60 cycle/sec)						<i>V<sub>m</sub></i>	<i>V</i>
1	8.1	8.1	8.1	8.1	8.1	Humidity is not		
2	15.8	15.8	15.8	15.8	15.8	stated		
3	23.1	23.1	23.1	23.1	23.1		(100)	(100)
4	29.5	29.5	29.5	29.5	29.5			
5	34.6	34.6	34.6	34.6	34.6			
6	39.4	39.4	39.4	39.4	39.4	5.1	51.0	52.0
7	43.1	43.2	43.3	43.5	43.7			
8	46.5	46.7	47.3	47.5	47.8	7.6	62.5	63.0
9	49.5	50.1	51.0	51.3	51.6			
10	52.0	53.0	54.3	54.7	55.6			
12	56.9	58.4	61.1	61.6	62.1	10.2	76.5	73.5
14	62.2	64.3	67.0	68.0	69.3	12.7	88.3	82.5
16	67.7	70.6	73.6	74.8	76.5			
18	73.4	75.9	80.1	81.4	83.4	15.3	98.3	90.5
20	79.4	83.4	86.8	88.4	90.7			
25	94.1	99.1	103.3	106.0	108.2	A.C. is 60 cycle/sec		
30	109.4	115.8	121.0	123.6	126.4			
40	140.0	148.6	153.3	157.0	162.1			
50				192				
75				280				
280				1040				

## LITERATURE

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## DIELECTRIC CONSTANT AND DIELECTRIC STRENGTH OF SINGLE CRYSTALS, MIXTURES AND SOLUTIONS, PURE ORGANIC COMPOUNDS, AND MISCELLANEOUS MATERIALS\*

L. HARTSHORN, C. C. HARRIS, J. A. HEY, T. I. JONES, AND A. G. MILLIGAN

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Dielectric constant:	Constante diélectrique:	Dielektrizitätskonstante:	Costante dielettrica:	
Standard liquids. Hartshorn.	Liquides étalons. Hartshorn.	Normalflüssigkeiten. Hartshorn.	Liquidi campione. Hartshorn.....	82
Pure organic gases and vapors. Jones.	Gaz et vapeurs organiques purs. Jones.	Reine organische Gase und Dämpfe. Jones.	Gas e vapori organici puri. Jones.....	82
Mixtures of hydrogen and nitrogen. Harris.	Mélanges d'hydrogène et d'azote. Harris.	Mischungen von Wasserstoff und Stickstoff. Harris.	Miscela di idrogeno e azoto. Harris.....	83
Pure organic liquids and solids. Hartshorn and Milligan.	Liquides et solides organiques purs. Hartshorn et Milligan.	Reine organische Flüssigkeiten und feste Stoffe. Hartshorn und Milligan.	Liquidi e solidi organici puri. Hartshorn e Milligan.....	83
Glycerol. Hartshorn.	Glycérine. Hartshorn.	Glycerin. Hartshorn.	Glicerina. Hartshorn..	97
Dispersion and absorption: organic compounds and solutions. Hartshorn.	Dispersion et absorption: composés et solutions organiques. Hartshorn.	Dispersion und Absorption: organische Verbindungen und Lösungen. Hartshorn.	Dispersione e assorbimento: composti e soluzioni organici. Hartshorn.....	97
Crystals. Hey.	Cristaux. Hey.	Kristalle. Hey.	Cristalli. Hey.....	98
Binary mixtures and solutions. Harris.	Mélanges binaires et solutions. Harris.	Binäre Mischungen und Lösungen. Harris.	Miscela binarie e soluzioni. Harris.....	100
Solutions of oleates. Harris.	Solutions d'oléates. Harris.	Oleat-Lösungen. Harris.	Soluzioni di oleati. Harris.....	104
Solutions at temperatures below $-100^{\circ}\text{C}$ . Harris.	Solutions à des températures inférieures à $-100^{\circ}\text{C}$ . Harris.	Lösungen bei Temperaturen unterhalb $-100^{\circ}\text{C}$ . Harris.	Soluzioni a temperature inferiori a $-100^{\circ}\text{C}$ . Harris.....	104
Colloidal suspensions in water. Harris.	Suspensions colloïdales dans l'eau. Harris.	Kolloidale Suspensionen in Wasser. Harris.	Sospensioni colloïdali in acqua. Harris.....	105
Miscellaneous materials. Hartshorn.	Matières diverses. Hartshorn.	Verschiedene Materialien. Hartshorn.	Materiali vari. Hartshorn.....	105
Variation with pressure: pure organic liquids. Hartshorn.	Variation avec la pression: liquides organiques purs. Hartshorn.	Änderung mit dem Druck: reine organische Flüssigkeiten. Hartshorn.	Variatione con la pressione: liquidi organici puri. Hartshorn.....	105
Effect of magnetic field. Hartshorn.	Effet du champ magnétique. Hartshorn.	Einfluss des magnetischen Feldes. Hartshorn.	Effetto di un campo magnetico. Hartshorn	105
Effect of electric field. Hartshorn.	Effet du champ électrique. Hartshorn.	Einfluss des elektrischen Feldes. Hartshorn.	Effetto di un campo elettrico. Hartshorn.	106
Dielectric strength: pure organic liquids. Hartshorn.	Cohésion diélectrique: liquides organiques purs. Hartshorn.	Dielektrische Festigkeit: reine organische Flüssigkeiten. Hartshorn.	Rigidità dielettrica: liquidi organici puri. Hartshorn.....	106

\* Industrial materials (Vol. II) are excluded from this section; for  $\text{CS}_2$ , v. p. 75.

\* Les matières industrielles (Vol. II) sont exclues de cette section; pour  $\text{CS}_2$ , v. p. 75.

\* Technische Materialien (Bd. II) sind in diesem Abschnitt nicht enthalten; für  $\text{CS}_2$  siehe S. 75.

\* I materiali industriali (Vol. II) non sono compresi; per  $\text{CS}_2$ , v. p. 75.



## SYMBOLS

In addition to the symbols and abbreviations defined in Vol. I, p. 16, and those defined where used, the following symbols will be used throughout this section:

Audio	Indicates that the frequency of the field employed in determination of $\epsilon$ lies within the range of audition.
$k'$	Index of absorption; see Vol. I, p. 34, "Absorption."
$\epsilon$	Dielectric constant.
$\nu$	Frequency.
$\partial_t$	100 ( $\partial\epsilon/\partial t$ ) at temperature $t$ .
(10 to 45)	For values of $t$ lying between 10 and 45°C.
3; 8	For the range 3 to 8.
$6.76 \pm 4$	$6.76 \pm 0.04$ .
$6.76 \pm 0.1$	$6.76 \pm 0.10$ .

TABLE 1.—STANDARD LIQUIDS

The substances included in this table are suitable for calibrating apparatus used for measuring dielectric constants. Values given for  $\partial\epsilon/\partial t$  are suitable for use over range of frequency indicated, and over ordinary range of temperature, say from 0 to 30°C; for more extreme temperatures, see Table 4. Frequency,  $\nu = A \times 10^8$ . Unit of  $\epsilon = 1$  cgse unit; of  $\partial\epsilon/\partial t = 1$  cgse unit per 1°C; of  $\nu (= A \times 10^8) = 1$  cycle/sec.

		$\epsilon_{20}^{\circ}$	$\partial\epsilon/\partial t$	Range				Lit.
				A	n	A	n	
$C_6H_6$	Benzene.....	2.283 $\pm 0.002$	-0.0019	5	2	5	8	(34, 75, 77, 183, 188)
Probably best. Colley (34) found dispersion in range $5.5 \times 10^8$ to $6 \times 10^8$ , and observed that in this range value found for $\epsilon$ varied greatly with the decrement; see Fig. 1.								
$C_6H_4(CH_3)_2$	m-Xylene.....	2.374 $\pm 0.002$	-0.0019	5	2	4	8	(42, 87, 147, 77, 183)
$(C_2H_5)_2O$	Ethyl ether.....	4.335 $\pm 0.005$	-0.019	0	0	4	8	(42, 49, 86, 87, 136, 177, 183)
Changes with time are liable to occur								
$C_6H_5NH_2$	Aniline.....	7.21 $\pm 0.05$	-0.025	0	0	4	8	(95, 133, 183)
Not very good. Impurities produce great effect								
$(CH_3)_2CO$	Acetone.....	21.3 $\pm 0.1$	-0.096 $\pm 2$	0	0	4	8	(34, 49, 75, 95, 189, 191)
Dispersion bands in range $4.3 \times 10^8$ to $4.6 \times 10^8$ (34)								
$C_6H_5CH_2NO_2$	o-Nitrotoluene..	27.42 $\pm 0.1$	-0.15	Audio				(183)
Value not known accurately at higher frequencies								
$C_6H_5NO_2$	Nitrobenzene...	35.7 $\pm 0.3$	-0.18	0	0	1	6	(92, 183, 191)

TABLE 2.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF PURE ORGANIC GASES AND VAPORS: PRESSURE OF 1 NORMAL ATMOSPHERE;  $\epsilon = 1 + \Delta \times 10^{-3}$ 

C-Table. The C-Arrangement; v. Vol. III, p. viii

		$\Delta$	$t, ^\circ C$	Lit.
$CCl_4$	Carbon tetrachloride....	3.0	110	(10)
		2.7	110	(160.1)
$CHCl_3$	Chloroform.....	4.2	120	(10)
		3.8	10	(160.1)
$CH_2Cl_2$	Methylene chloride....	6.5	100	(10)
		6.0	100	(160.1)
$CH_3Br$	Methyl bromide.....	6.8	100	(142)
$CH_3Cl$	Methyl chloride.....	6.9	100	(142)
		6.4	100	(160.1)
$CH_3I$	Methyl iodide.....	6.3	100	(142)
$CH_3NO_2$	Nitromethane.....	24.7	100	(142)
$CH_4$	Methane.....	0.94*	0	(21.1, 107, 148.1)
		0.89	0	(142)
		1.01	0	(160.1)

TABLE 2.—(Continued)

		$\Delta$	$t, ^\circ C$	Lit.
$CH_3O$	Methyl alcohol.....	5.7	100	(142)
		6.1	100	(10, 97, 113)
$CH_3N$	Methylamine.....	3.8	100	(142)
$C_2H_2$	Acetylene.....	1.34*	0	(173.1)
$C_2H_3Br$	Vinyl bromide.....	8.1	20	(142)
$C_2H_3ClO$	Acetyl chloride.....	21.7	20	(142)
$C_2H_3N$	Acetonitrile.....	26.4	100	(142)
$C_2H_4$	Ethylene.....	1.44 $\pm 1$	0	(107, 142, 173.1)
$C_2H_5O$	Acetaldehyde.....	21.3	20	(142)
$C_2H_5O_2$	Methyl formate.....	7.3	100	(113)
$C_2H_5Br$	Ethyl bromide.....	14.6	15.5	(107)
		13.9	20	(142)
		8.9	100	(142)
$C_2H_5Cl$	Ethyl chloride.....	14.7	15.5	(107)
		13.2	20	(142)
		8.5	100	(142)
$C_2H_5I$	Ethyl iodide.....	14.0	20	(142)
		8.9	100	(142)
$C_2H_5NO_2$	Nitroethane.....	28.1	100	(142)
$C_2H_6$	Ethane.....	1.50*	0	(173.1)
$C_2H_6O$	Ethyl alcohol.....	6.5	100	(10)
		6.9	100	(113)
		6.1	100	(142)
$C_2H_6O$	Methyl ether.....	7.4	0	(10)
		4.1	100	(142)
$C_2H_7N$	Dimethylamine.....	3.3	100	(142)
$C_2H_7N$	Ethylamine.....	4.3	100	(142)
$C_3H_5Br$	3-Bromopropylene....	12.9	20	(142)
$C_3H_5Cl$	2-Chloropropylene....	10.2	20	(142)
$C_3H_5Cl$	3-Chloropropylene....	12.8	20	(142)
$C_3H_5N$	Propionitrile.....	28.3	100	(142)
$C_3H_6O$	Acetone.....	25.9	20	(142)
		15.0	100	(142)
$C_3H_6O_2$	Ethyl formate.....	8.3	100	(113)
$C_3H_6O_2$	Methyl acetate.....	7.7	100	(113)
$C_3H_7Br$	n-Propyl bromide.....	9.8	100	(142)
$C_3H_7Cl$	Isopropyl chloride....	15.2	20	(142)
		9.8	100	(142)
$C_3H_7Cl$	n-Propyl chloride....	14.3	20	(142)
		9.3	100	(142)
$C_3H_7N$	Allylamine.....	4.2	100	(142)
$C_3H_7N$	n-Propylamine.....	5.0	100	(142)
$C_4H_8$	Butylene.....	3.19	0	(173.1)
		2.91	21	(173.1)
		2.22	100	(173.1)
		1.74	193	(173.1)
$C_4H_9Cl$	n-Butyl chloride.....	10.1	100	(142)
$C_4H_{10}O$	Ethyl ether.....	7.0	16.5	(107)
		4.9	100	(113)
		5.2	100	(10)
$C_4H_{11}N$	Diethylamine.....	3.8	100	(142)
$C_5H_{10}$	$\beta$ -Amylene.....	2.8	100	(142)
$C_5H_{10}$	2-Methyl-2-butene....	2.8	100	(142)
$C_5H_{10}O_2$	Ethyl propionate....	14.0	120	(113)
$C_5H_{12}$	n-Pentane.....	2.5	100	(142)
$C_5H_{12}$	Isopropylethane.....	2.6	100	(142)
$C_6H_6$	Benzene.....	2.8	100	(10, 113, 142)
$C_6H_{11}N$	Triethylamine.....	4.2	100	(142)
$C_7H_8$	Toluene.....	4.8	126	(113)
$C_7H_{16}$	n-Heptane.....	3.5	100	(142)

\* $(\epsilon - 1)$  is proportional to  $p/T$ ,  $p$  = pressure,  $T$  = absolute temperature



TABLE 3.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF MIXTURES OF HYDROGEN AND NITROGEN (178, 179)

Audio frequency; 20°C;  $P_{H_2}$ ,  $P_{N_2}$  = partial pressures of the  $H_2$ ,  $N_2$ ;  $P$  = total pressure of the mixture. Unit of  $P$ ,  $P_{H_2}$ ,  $P_{N_2}$  = 1 atmosphere; of  $\epsilon$  = 1 cgse unit.

$P$	$P_{H_2}$	$P_{N_2}$	$\epsilon$	$P$	$P_{H_2}$	$P_{N_2}$	$\epsilon$
1.0	0.7	0.3	1.0003	39.0	14.0	24.8	1.0172
1.0	0.6	0.4	1.0004	39.3	24.8	14.3	1.0138
1.0	0.4	0.6	1.0004	39.8	27.6	11.9	1.0133
20.4	14.2	6.2	1.0069	55.9	38.8	16.6	1.0186
20.7	7.4	13.3	1.0092	58.5	21.0	36.9	1.0255
20.8	13.1	7.7	1.0074	60.3	38.0	21.7	1.0211

TABLE 4.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF PURE ORGANIC COMPOUNDS, AND ITS VARIATION WITH TEMPERATURE ( $t$ ) AND FREQUENCY ( $\nu$ ): LIQUIDS AND SOLIDS

All values of  $\epsilon$  have been reduced to a basis which accords with the values given for the standard liquids in Table 1.

For symbols, see p. 82; also, B. P. = boiling point, crit. = critical temperature, M. P. = melting point,  $\nu$  = liquid is under pressure of its saturated vapor.  $\nu = A \times 10^8$ . Unit of  $\epsilon$  = 1 cgse unit; of  $\nu$  = 1 cycle/sec; of  $t$  = 1°C.

C-Table. The C-Arrangement; v. Vol. III, p viii  
Immediately after oleic acid are data for a few olcates. Some metallic organic compounds are also given in the table.

$\epsilon$	$t$	$A$	$n$	Lit.
CCl <sub>4</sub> , Carbon tetrachloride				
2.24*	20	1	3; 8	(77, 80, 99, 183)
2.10	76.7 B. P.	Audio		(76)
CN <sub>4</sub> O <sub>8</sub> , Tetranitromethane				
2.13	20	Audio		(191)
2.15	5	Audio		(191)
<2.2	20	4	8	(189)
CHN, Hydrocyanic acid				
95 ± 4l	+ 21	3.6	8	(163)
2.48	- 25	3.6	8	(162)
3.05s	- 70	3.6	8	(162)
CHBr <sub>3</sub> , Bromoform; M. P. = 7.5°				
4.51 ± 5	20	Audio		(28, 186)
4.65 ± 5	8			(28)
4.45 ± 0.1	20	4	8	(41, 49)
4.73	25	1	6	(161.2)
CHCl <sub>3</sub> , Chloroform; M. P. = -63.2°				
5.05 ± 5†	20	Audio		(28, 42, 77, 116, 133, 136, 183)
2.76	-186			(87)
3.10	- 80			(87)
3.12	- 70			(87)
7.03	- 60			(87)
6.47	- 40			(87)
6.65	- 40			(77)
5.95	- 20			(17, 87)
6.00	- 20			(77)
5.48	0			(17, 87, 145)
5.49	0			(77)
5.05 ± 0.1	+ 20			(28, 42, 116, 133, 136, 183)
4.70	40			(87, 145, 177)
4.37	60			(76, 87, 145, 177)

\*  $\epsilon_t = -0.14$  (20 to 60) (77).

†  $\epsilon_{20} = -1.85$  (28, 87, 127).

TABLE 4.—Continued

$\epsilon$	$t$	$A$	$n$	Lit.
CHCl <sub>3</sub> —(Continued)				
3.85	100			(177)
3.46	140			(177)
3.05	180			(177)
4.95 ± 0.1	20	1	6	(87, 95)
4.93	20	6.7	7	(193.1)
4.95 ± 0.1	20	4	8	(49, 99)
CH <sub>2</sub> I <sub>2</sub> , Methylene iodide				
5.5 ± 0.1	19	Audio		(183)
5.1	21	5	8	(41)
CH <sub>2</sub> O <sub>2</sub> , Formic acid; M. P. = 8.4°				
62.0	15	2.5	7	(181)
2.41	-187			(38)
2.66	-182			(38)
2.70	-137			(38)
3.65	-118			(38)
4.80	-112			(38)
19.0s*	+ 2	4	8	(49)
58.5†	16	4	8	(49)
47.9	18.5	5	8	(41)
CH <sub>3</sub> I, Methyl iodide				
7.1 ± 0.1	20	Audio		(183)
6.48	42.35 B. P.	Audio		(76)
CH <sub>3</sub> NO, Formamide				
>84	20	4	8	(189)
CH <sub>3</sub> NO <sub>2</sub> , Nitromethane				
39.4 ± 2	20	Audio		(191)
45.2	0	Audio		(191)
27.75 ± 0.1	101 B. P.	Audio		(76)
38.9 ± 8	20	4	8	(164, 189)
CH <sub>3</sub> NO <sub>3</sub> , Methyl nitrate				
23.9 ± 5	18	3.6	8	(164)
CH <sub>4</sub> N <sub>2</sub> O, Urea				
3.5 ± 2	22	4	8	(174)
CH <sub>3</sub> O, Methyl alcohol; M. P. = -95° (see also Table 6)				
33.7 ± 1.0†	20	1	2; 6	(2, 64, 95, 110, 180)
3.25	-185			(38)
3.55	-170			(38)
4.0	-160			(38)
5.05	-140			(38)
66.8	-110			(2)
56.8	- 80			(2)
48.5	- 50			(2)
41.8	- 20			(2)
37.5	0			(2)
33.7 ± 1.0	+ 20			(2, 64, 95, 110, 180)
33.1 ± 0.5	20	4	8	(44, 49, 190)
12.4	17	5	9	(53)
25	17	7	9	(125)
10.8	17	8	9	(53)
7.9	17	17	9	(53)
CH <sub>3</sub> N, Methylamine				
<10.5	21	3.6	8	(164)
C <sub>2</sub> Cl <sub>4</sub> , Tetrachloroethylene				
2.37	16	6.7	7	(194)
2.46	21	3.6	8	(164)
C <sub>2</sub> N <sub>2</sub> , Cyanogen				
2.57 ± 5l	23	3.6	8	(164)

\*  $k' = 0.17$  (49). †  $k' = 0.08$  (49).

†  $\epsilon_{20} = -18$ ,  $A = 1$ ;  $n = 3; 8$  (2, 160).



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>2</sub>HBr<sub>3</sub>O, Bromal</b>				
7.6±2	21	5	8	(41)
<b>C<sub>2</sub>HCl<sub>3</sub>, Trichloroethylene</b>				
3.42±8	16	6.7	7	(194)
<b>C<sub>2</sub>HCl<sub>3</sub>O, Chloral; M. P. = -57.5°</b>				
7.58	-40			(127)
6.54	-20			(127)
5.69	0			(127)
4.94	+20			(127)
4.56	40			(127)
4.25	60			(127)
5.0	20	1	ca. 6	(127)
5.5	15	2.5	7	(181)
<b>C<sub>2</sub>HCl<sub>3</sub>O<sub>2</sub>, Trichloroacetic acid</b>				
4.55	61	Audio		(191)
<b>C<sub>2</sub>HCl<sub>5</sub>, Pentachloroethane</b>				
3.76	16	6.7	7	(194)
3.60	25	1	6	(161.2)
<b>C<sub>2</sub>H<sub>2</sub>Br<sub>2</sub>O, Bromoacetyl bromide</b>				
12.6±2	20	4	8	(189)
<b>C<sub>2</sub>H<sub>2</sub>Br<sub>4</sub>, Tetrabromoethane</b>				
7.1	20	Audio		(191)
8.6	2.5	Audio		(191)
<b>C<sub>2</sub>H<sub>2</sub>Cl<sub>2</sub>, Dichloroethylene</b>				
3.67*†	16	6.7	7	(194)
7.55*†	16	6.7	7	(194)
9.22‡	ca. 20	4	5	(61.1)
2.25	ca. 20	4	5	(61.1)
<b>C<sub>2</sub>H<sub>2</sub>I<sub>2</sub>, Diiodoethylene</b>				
4.46¶	83	4	5	(61.1)
3.19**	83	4	5	(61.1)
<b>C<sub>2</sub>H<sub>2</sub>Cl<sub>2</sub>O<sub>2</sub>, Dichloroacetic acid</b>				
8.8l	-10	Audio		(191)
8.2l	+20	Audio		(191)
7.8l	60	Audio		(191)
8.1s		Audio		(191)
10.7	20	5	8	(41)
<b>C<sub>2</sub>H<sub>2</sub>Cl<sub>4</sub>, sym.-Tetrachloroethane</b>				
7.83	25	1	6	(161.2)
8.20	20	6.7	7	(193.1, 194)
<b>C<sub>2</sub>H<sub>2</sub>BrO, Acetyl bromide</b>				
16.5±3	20	4	8	(189)
<b>C<sub>2</sub>H<sub>2</sub>ClO, Acetyl chloride</b>				
15.9	20	Audio		(191)
17.0	0	Audio		(191)
15.8±3	20	4	8	(189)
25.3	15	2.5	7	(181)
<b>C<sub>2</sub>H<sub>2</sub>ClO<sub>2</sub>, Chloroacetic acid</b>				
ca. 21s	20	Audio		(191)
ca. 20.0l	62	Audio		(191)
<b>C<sub>2</sub>H<sub>2</sub>Cl<sub>2</sub>O<sub>2</sub>, Chloral hydrate</b>				
13l††	65	4	8	(49)
3.8±0.03††	20	4	8	(49, 174)
<b>C<sub>2</sub>H<sub>3</sub>N, Acetonitrile</b>				
42.0	0	Audio		(191)
38.8	20	Audio		(76, 191)
26.2	81.6 B. P.	Audio		(76)
36.2±7	20	4	8	(163, 189)

\* Mixtures in which the *cis* and *trans* forms were separated as far as possible.† *Cis*. ‡ *Trans*. § *Cis*, pure, B. P. = 60.25°. || *Trans*, pure, B. P. = 48.35°.¶ *Cis*, M. P. = -13.8°.\*\* *Trans*, M. P. = +72°.††  $k' = 0.03$ .‡‡  $k' < 0.02$ .

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>2</sub>H<sub>3</sub>NO, Glycolic nitrile</b>				
69±1	20	4	8	(189)
<b>C<sub>2</sub>H<sub>3</sub>NS, Methyl thiocyanate</b>				
35.9±7	20	4	8	(54, 124, 189)
<b>C<sub>2</sub>H<sub>3</sub>NS, Methyl isothiocyanate</b>				
19.7±7	37	4	8	(54, 124, 189)
<b>C<sub>2</sub>H<sub>4</sub>Br<sub>2</sub>, Ethylene bromide; M. P. = +10°</b>				
4.865±0.015	18	Audio		(42, 91, 183)
2.69	-185			(68)
2.70	-150			(68)
2.77	-80			(68)
2.94	-60			(68)
2.97	-50			(68)
2.98	-30			(68)
4.865±.015	+18			(42, 91, 183)
4.09	131.3 B. P.			(76)
4.70	25	1	6	(161.2)
6.3	20	5	8	(41)
<b>C<sub>2</sub>H<sub>4</sub>Cl<sub>2</sub>, Ethylene chloride; M. P. = -35.5°</b>				
10.5±3	20	1	3; 6	(95, 110, 183, 187, 191)
11.6	0	Audio		(191)
10.44	20	Audio		(191)
10.13	25	1	3	(80.1)
9.4	50	Audio		(191)
9.96	20	6.7	7	(193.1)
9.3	20	5	8	(41)
<b>C<sub>2</sub>H<sub>4</sub>Cl<sub>2</sub>, Ethylidene chloride</b>				
10.9	16	Audio		(110)
9.1	18	5	8	(41)
<b>C<sub>2</sub>H<sub>4</sub>O, Acetaldehyde</b>				
21.6±4	20	4	8	(49, 190)
22.2±4	10	4	8	(49)
<b>C<sub>2</sub>H<sub>4</sub>O, Ethylene oxide</b>				
13.9	-1	Audio		(191)
<b>C<sub>2</sub>H<sub>4</sub>OS, Thioacetic acid</b>				
13.0	20	4	8	(189)
17.3	21	3.6	8	(54)
<b>C<sub>2</sub>H<sub>4</sub>O<sub>2</sub>, Acetic acid</b>				
7.14±0.1	17	Audio		(91)
7.1	17	1.3	8	(44)
6.4±1*	20	4	8	(41, 44, 49)
4.13†	2	4	8	(49)
<b>C<sub>2</sub>H<sub>4</sub>O<sub>2</sub>, Methyl formate</b>				
8.27	20	Audio		(191)
9.25	0	Audio		(191)
8.9	+19	4	8	(49)
2.56	-194*	4.7	5	(89)
<b>C<sub>2</sub>H<sub>5</sub>Br, Ethyl bromide</b>				
9.45	20	1	3; 6	(80, 183, 191)
10.5	1.4	Audio		(191)
8.81	38.4 B. P.	Audio		(76)
9.1±3	18	4	8	(49)
<b>C<sub>2</sub>H<sub>5</sub>Cl, Ethyl chloride</b>				
6.29vp	170	Audio		(62)
6.06vp	179	Audio		(62)
5.60vp	180	Audio		(62)
4.68vp	185.5 crit.	Audio		(62)

\*  $k' = 0.07$ .†  $k' = 0.10$ .



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>2</sub>H<sub>4</sub>ClO, Ethylenechlorohydrin</b>				
25.8	24.5	Audio		(76)
13.2	132.0 B. P.	Audio		(76)
<b>C<sub>2</sub>H<sub>5</sub>I, Ethyl iodide</b>				
7.4±1	20	Audio		(49)
7.4±1	20	4	8	(49)
<b>C<sub>2</sub>H<sub>5</sub>NO, Acetaldoxime</b>				
2.98	22.6	Audio		(191)
3.4	20	4	8	(41, 189)
<b>C<sub>2</sub>H<sub>5</sub>NO, Acetamide</b>				
60.3±1.0†	83 M. P.	4	8	(189)
60.4±1.0†	77	4	8	(189)
4.08	20	4	8	(189)
7.28	22	4	8	(174)
<b>C<sub>2</sub>H<sub>5</sub>NO<sub>2</sub>, Nitroethane</b>				
30.0±6	18	3.6	8	(164)
<b>C<sub>2</sub>H<sub>5</sub>NO<sub>3</sub>, Ethyl nitrate; M. P. = -112°</b>				
19.7	20	Audio		(49, 189, 191)
2.78	-190	1.2	2	(38)
2.92	-176	1.2	2	(38)
21.8	0	Audio		(191)
19.7	+ 20	Audio		(49, 189, 191)
17.2	50	Audio		(191)
19.7±3	20	4	8	(49, 189)
<b>C<sub>2</sub>H<sub>5</sub>N<sub>2</sub>O, Nitrosodimethylamine</b>				
54±1	20	4	8	(189)
<b>C<sub>2</sub>H<sub>5</sub>O, Ethyl alcohol; M. P. = -114° (see also Fig. 2 and Table 6)</b>				
25.7±2*	20	Audio		(76, 110, 133, 183, 191)
3.128	-172			(37)
2.78	< -150			(2)
55.5	-120			(2)
45.1	- 80			(2)
38.1	- 50			(2)
32.4	- 20			(2)
28.9	0			(145, 191)
25.7±2	+ 20			(76, 110, 133, 183, 191)
22.7	40			(145, 191)
20.2	60			(145, 191)
23.2±5	20	1	6	(135, 124.1)
23.9	20	6	7	(64)
24.2±7	20	2.5	7	(181)
22.0±4†	+ 20	4	8	(49, 174, 190)
3.12	-170	1	2	(37)
<b>C<sub>2</sub>H<sub>6</sub>O<sub>2</sub>, Glycol</b>				
47.0	0	Audio		(191)
41.2	20	Audio		(191)
35.6	50	Audio		(191)
35.2±7	20	4	8	(190)
<b>C<sub>2</sub>H<sub>6</sub>O<sub>2</sub>S, Dimethyl sulfate</b>				
55.0	20	Audio		(191)
58.9	0	Audio		(191)
47.4±9	20	4	8	(189)
<b>C<sub>2</sub>H<sub>6</sub>S, Dimethyl sulfide</b>				
6.8±2	20	4	8	(189)
<b>C<sub>2</sub>H<sub>5</sub>S, Ethylmercaptan</b>				
8.0	ca. 20	4	8	(9)
<b>C<sub>2</sub>H<sub>7</sub>N, Ethylamine</b>				
6.8±2	21	3.6	8	(164)

\*  $\partial_{10} = -16$  (2, 76, 135, 145, 191). †  $k' = 0.21$  (49, 174, 190) ‡ Supercooled.

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>2</sub>H<sub>8</sub>N<sub>2</sub>, Ethylenediamine</b>				
16.0±4	18	3.6	8	(124)
<b>C<sub>3</sub>H<sub>7</sub>N<sub>2</sub>, Malonic nitrile</b>				
47.2±9	36	3.6	8	(54)
<b>C<sub>3</sub>H<sub>7</sub>NO<sub>2</sub>, Cyanoacetic acid</b>				
ca. 33.4	4	Audio		(191)
<b>C<sub>3</sub>H<sub>4</sub>Cl<sub>2</sub>O, 1, 1-Dichloroacetone</b>				
14.6	20	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>Br, Allyl bromide</b>				
7.0	19	Audio		(191)
7.4	1	Audio		(191)
<b>C<sub>3</sub>H<sub>5</sub>BrO<sub>2</sub>, <math>\alpha</math>-Bromopropionic acid</b>				
11.0±8	20	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>Br<sub>3</sub>, 1, 2, 3-Tribromopropane</b>				
6.4	20	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>Cl, Allyl chloride</b>				
8.2	20	Audio		(191)
8.7	1	Audio		(191)
7.3	20	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>ClO, Chloroacetone</b>				
29.8±6	20	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>ClO, Epichlorohydrin</b>				
25.7	0	Audio		(191)
22.9	20	Audio		(191)
21.2	20	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>ClO<sub>2</sub>, Ethyl chloroformate</b>				
11.3±3	20	4	8	(41, 189)
<b>C<sub>3</sub>H<sub>5</sub>ClO<sub>2</sub>, Methyl chloroacetate</b>				
12.9±4	20	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>Cl<sub>3</sub>, 1, 2, 3-Trichloropropane</b>				
7.5	21	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>I, Allyl iodide</b>				
6.1	19	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>N, Propionitrile</b>				
31.6	0	Audio		(191)
27.7	20	Audio		(191)
24.6	50	Audio		(191)
27.5±5	20	4	8	(9, 163, 189)
<b>C<sub>3</sub>H<sub>5</sub>NO, Lactonitrile</b>				
38.4±7	20	4	8	(189)
<b>C<sub>3</sub>H<sub>5</sub>NS, Ethyl thiocyanate</b>				
35.3	0	Audio		(191)
29.6	20	Audio		(191)
29.2±5	20	3.6	8	(54, 124)
27.0	20	4	8	(189)
<b>C<sub>3</sub>H<sub>5</sub>NS, Ethyl isothiocyanate</b>				
23.8	0	Audio		(191)
19.7	20	Audio		(191)
19.7±4	20	4	8	(54, 124, 189)
<b>C<sub>3</sub>H<sub>5</sub>Br<sub>2</sub>, 1, 2-Dibromopropane</b>				
4.35±0.1	20	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>Br<sub>2</sub>O, 1, 2-Dibromopropyl alcohol</b>				
9.1±2	21	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>Cl<sub>2</sub>O, 1, 1-Dichloroisopropyl alcohol</b>				
12.0±3	20	5	8	(41)
<b>C<sub>3</sub>H<sub>5</sub>O, Allyl alcohol</b>				
21.0±.*	21	4	8	(41, 48, 49)
21.6±6	15	2.5	7	(181)
<b>C<sub>3</sub>H<sub>5</sub>O, Propionaldehyde</b>				
18.9±4	17	4	8	(49)
14.4	15	2.5	7	(181)

\*  $k' = 0.07$ .



TABLE 4.—(Continued)

$\epsilon$	$t$	A	n	Lit.
<b>C<sub>3</sub>H<sub>6</sub>O, Acetone; M. P. = -94.3°; for dispersion and absorption, see (34)</b>				
21.4*	+ 20	Audio	(191)	
2.62	-184		(38)	
2.49	-181		(38)	
2.66	-151.5		(38)	
4.63	-129		(38)	
31.0	- 80		(1)	
27.9	- 50		(1)	
26.1	- 30		(75)	
23.3	0		(76)	
21.4±1	+ 20		(34, 49, 75, 95, 181, 189, 191)	
18.7	50		(75)	
17.68	56.15 B. P.	Audio	(76)	
21.9±6	20	1	6	(75, 95, 124.1)
21.3	20	2.5	7	(181)
21.22	20	4	8; 9	(34, 49, 189)
<b>C<sub>3</sub>H<sub>6</sub>O<sub>2</sub>, Propionic acid</b>				
3.19	19	Audio	(91)	
3.21±6†	17	4	8	(41, 49)
<b>C<sub>3</sub>H<sub>6</sub>O<sub>2</sub>, Ethyl formate</b>				
9.1	14	Audio	(110, 180)	
8.4±1	+ 19	4	8	(49)
2.40	-192	4.7	5	(89)
<b>C<sub>3</sub>H<sub>6</sub>O<sub>2</sub>, Methyl acetate</b>				
7.3±2‡	20	Audio	(110, 119, 180)	
7.2±2	20	4	8	(49)
<b>C<sub>3</sub>H<sub>6</sub>O<sub>2</sub>, Lactic acid</b>				
23±1	19	Audio	(119)	
19.4±2§	19	4	8	(49)
<b>C<sub>3</sub>H<sub>7</sub>Br, Propyl bromide</b>				
7.2±2	20	5	8	(41)
<b>C<sub>3</sub>H<sub>7</sub>Cl, Propyl chloride</b>				
7.7±2	20	5	8	(41)
<b>C<sub>3</sub>H<sub>7</sub>ClO<sub>2</sub>, 3-Chloro-1, 2-dihydroxypropane</b>				
31	20	Audio	(191)	
38.6	0	Audio	(191)	
15.1	20	5	8	(41)
<b>C<sub>3</sub>H<sub>7</sub>NO<sub>2</sub>, Urethane</b>				
13.8±2‡	60	3.6	8	(164)
3.24±6§	23	3.6	8	(164)
<b>C<sub>3</sub>H<sub>7</sub>NO<sub>2</sub>, Isopropyl nitrite</b>				
ca. 11.5	19	3.3	8	(164)
<b>C<sub>3</sub>H<sub>7</sub>NO<sub>2</sub>, Propyl nitrate</b>				
14.2±3	18	3.6	8	(164)
<b>C<sub>3</sub>H<sub>8</sub>O, n-Propyl alcohol; M. P. = -127° (see also Table 6)</b>				
21.8±4	20	Audio	(2, 76, 110, 180)	
2.753	< -150		(2)	
47.0	-126		(2)	
41.0	-100		(2)	
37.1	- 80		(2)	
32.0	- 50		(2)	
27.1	- 20		(2)	
24.5			(2)	

\*  $\delta_{20} = -9.6 \pm 2$  (1, 48, 75, 191).†  $n_D = 0.03$ .‡  $\delta_{20} = -6$  (119). §  $k' = 0.25$ . ||  $\delta_{20} = -13$ .

TABLE 4.—(Continued)

$\epsilon$	$t$	A	n	Lit.
<b>C<sub>2</sub>H<sub>5</sub>O.—(Continued)</b>				
21.8±4	+ 20			(2, 76, 110, 180)
11.83	97.19 B. P.			(76)
19.8	20	2.5	7	(181)
12.3±5*	20	4	8	(49, 160, 174)
<b>C<sub>3</sub>H<sub>8</sub>O, Isopropyl alcohol</b>				
26±1	20	Audio	(119)	
19.8	15	2.5	7	(181)
15.7±5	20	4	8	(48, 49)
<b>C<sub>3</sub>H<sub>8</sub>O<sub>2</sub>, Methylal</b>				
2.7	20	4	8	(189)
<b>C<sub>3</sub>H<sub>8</sub>O<sub>3</sub>, Glycerol (see Table 5)</b>				
<b>C<sub>3</sub>H<sub>7</sub>BO<sub>3</sub>, Trimethyl borate</b>				
8.2±2	20	4	8	(189)
<b>C<sub>3</sub>H<sub>7</sub>N, Isopropylamine</b>				
5.5±1	20	3.6	8	(164)
<b>C<sub>3</sub>H<sub>7</sub>N, Trimethylamine</b>				
2.99±4	4	3.6	8	(164)
<b>C<sub>4</sub>H<sub>4</sub>O<sub>3</sub>, Maleic anhydride</b>				
51.0±1.0	60	4	8	(189)
<b>C<sub>4</sub>H<sub>4</sub>N<sub>2</sub>, Ethylene cyanide</b>				
58.3±1.0	58	4	8	(189)
62.4±1.2‡	60	3.6	8	(164)
66.6±1.3§	23	3.6	8	(164)
<b>C<sub>4</sub>H<sub>4</sub>S, Thiophene</b>				
2.76±5	16	Audio	(183)	
2.80	20	3.6	8	(54)
2.60	50	3.6	8	(54)
<b>C<sub>4</sub>H<sub>5</sub>ClO, Butyl chloral</b>				
10.0	18	5	8	(41)
<b>C<sub>4</sub>H<sub>5</sub>ClO<sub>2</sub>, Ethyl trichloroacetate</b>				
8.4	0	Audio	(191)	
7.8	20	Audio	(191)	
6.7	60	Audio	(191)	
<b>C<sub>4</sub>H<sub>5</sub>N, Crotonic nitrile</b>				
36.1††	ca. 20	4	5	(61.1)
28.1†‡	ca. 20	4	5	(61.1)
<b>C<sub>4</sub>H<sub>5</sub>NO<sub>2</sub>, Methyl cyanoacetate</b>				
29.4±6	20	4	8	(189)
<b>C<sub>4</sub>H<sub>5</sub>NS, Allyl isothiocyanate</b>				
17.5±3	18	3.6	8	(54, 124)
<b>C<sub>4</sub>H<sub>5</sub>ClO<sub>2</sub>, Ethyl dichloroacetate</b>				
11.7	0	Audio	(191)	
10.4	20	Audio	(191)	
<b>C<sub>4</sub>H<sub>6</sub>O<sub>3</sub>, Acetic anhydride</b>				
20.5	20	Audio	(191)	
22.5	0	Audio	(191)	
18.3±4	20	4	8	(189)
20.0	20	5	8	(41)
<b>C<sub>4</sub>H<sub>6</sub>O<sub>4</sub>, Dimethyl oxalate</b>				
ca. 9.2‡	65	4	8	(49)
ca. 3.18	20	4	8	(49)
<b>C<sub>4</sub>H<sub>6</sub>O<sub>6</sub>, Tartaric acid</b>				
35.9	15	2.5	7	(181)
<b>C<sub>4</sub>H<sub>7</sub>Br, sym.-Dimethylbromoethylene</b>				
6.76	ca. 20	4	5	(61.1)
5.38¶	ca. 20	4	5	(61.1)

\*  $k' = 0.41$ .† CH<sub>3</sub>, CN, cis, trans isomers.

‡ B. P. = 107.7; 108.2°. § B. P. = 121.7; 122.1°.

|| CH<sub>3</sub> and Br in trans, B. P. = 93.6; 93.9°.¶ CH<sub>3</sub> and Br in cis, B. P. = 85.8; 85.9°.



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>4</sub>H<sub>7</sub>Br, 1-Bromobutylene</b>				
5.89*†	ca. 20	4	5	(61.1)
5.05*†	ca. 20	4	5	(61.1)
<b>C<sub>4</sub>H<sub>7</sub>BrO<sub>2</sub>, 1-Bromobutyric acid</b>				
7.22	20	5	8	(41)
<b>C<sub>4</sub>H<sub>7</sub>BrO<sub>2</sub>, 1-Bromoisobutyric acid (supercooled)</b>				
9.81	<29	5	8	(41)
<b>C<sub>4</sub>H<sub>7</sub>ClO<sub>2</sub>, Ethyl chloroacetate</b>				
11.4	20	5	8	(41)
<b>C<sub>4</sub>H<sub>7</sub>ClO<sub>2</sub>, Propyl chloroformate</b>				
11.2	20	5	8	(41)
<b>C<sub>4</sub>H<sub>7</sub>N, Butyronitrile; slight absorption</b>				
20.7±4	21	3.6	5	(163)
<b>C<sub>4</sub>H<sub>7</sub>N, Isobutyronitrile; slight absorption</b>				
20.8±4	24	3.6	5	(163)
<b>C<sub>4</sub>H<sub>8</sub>Br<sub>2</sub>, 2, 3-Dibromobutane</b>				
5.70±0.1	20	5	8	(41)
<b>C<sub>4</sub>H<sub>8</sub>Br<sub>2</sub>, Isobutylene bromide</b>				
4.05±0.1	20	5	8	(41)
<b>C<sub>4</sub>H<sub>8</sub>N<sub>2</sub>O<sub>2</sub>, Succinamide</b>				
2.9±2	22	4	8	(174)
<b>C<sub>4</sub>H<sub>8</sub>O, Butyraldehyde</b>				
13.4	26	Audio		(76)
10.78	77.0 B. P.	Audio		(76)
<b>C<sub>4</sub>H<sub>8</sub>O, Methyl ethyl ketone</b>				
18.45±0.1	23	Audio		(76)
14.46	79.6 B. P.	Audio		(76)
18.4±4	15	2.5	7	(181)
18.1±3	17	4	8	(49)
<b>C<sub>4</sub>H<sub>8</sub>O<sub>2</sub>, <i>n</i>-Butyric acid</b>				
2.9±4	16	Audio		(91)
2.85±6	20	4	8	(41, 49)
<b>C<sub>4</sub>H<sub>8</sub>O<sub>2</sub>, Isobutyric acid</b>				
2.68	16	Audio		(91)
2.65±5	20	4	8	(49)
3.22	20	5	8	(41)
<b>C<sub>4</sub>H<sub>8</sub>O<sub>2</sub>, Ethyl acetate</b>				
6.4±1§	20	Audio		(76, 110, 116, 119, 180)
5.30	77.15 B. P.	Audio		(76)
6.0±1	+ 20	4	8	(49)
2.48	-194	4.7	5	(89)
<b>C<sub>4</sub>H<sub>8</sub>O<sub>2</sub>, Methyl propionate</b>				
5.47±0.1	19	5	8	(41)
<b>C<sub>4</sub>H<sub>8</sub>O<sub>2</sub>, Propyl formate</b>				
9.10	23	Audio		(110)
7.9±2	+ 19	4	8	(49)
2.39	-193.5	4.7	5	(89)
<b>C<sub>4</sub>H<sub>9</sub>Br, <i>n</i>-Butyl bromide</b>				
6.60±0.1	19.8	5	8	(41)
<b>C<sub>4</sub>H<sub>9</sub>Br, Isobutyl bromide</b>				
6.65±0.1	20.7	5	8	(41)
<b>C<sub>4</sub>H<sub>9</sub>Br, <i>tert</i>-Butyl bromide</b>				
8.55±0.15	20.4	5	8	(41)
<b>C<sub>4</sub>H<sub>9</sub>Cl, Butyl chloride</b>				
9.65		Audio		(119)
<b>C<sub>4</sub>H<sub>9</sub>Cl, Isobutyl chloride</b>				
7.1		Audio		(119)
<b>C<sub>4</sub>H<sub>9</sub>I, <i>n</i>-Butyl iodide</b>				
6.15±0.1	25	Audio		(76)
4.52±0.1	129.9 B. P.	Audio		(76)

\* *Cis, trans* isomers.  
† B. P. = 86.0; 86.2°.

† B. P. = 94.6; 94.8°.  
§  $\delta_{20} = -1.5$ .

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>4</sub>H<sub>9</sub>I, Isobutyl iodide</b>				
5.8±0.1	20	5	8	(41)
<b>C<sub>4</sub>H<sub>9</sub>I, <i>tert</i>-Butyl iodide</b>				
6.3±0.1	20	5	8	(41)
<b>C<sub>4</sub>H<sub>9</sub>NO, Methyl ethyl ketoxime</b>				
3.4	20	5	8	(41)
<b>C<sub>4</sub>H<sub>9</sub>NO<sub>3</sub>, Isobutyl nitrate</b>				
11.9±2	19	3.6	8	(164)
<b>C<sub>4</sub>H<sub>10</sub>Hg, Mercury diethyl</b>				
2.3±2	20	4	8	(124, 189)
<b>C<sub>4</sub>H<sub>10</sub>O, <i>n</i>-Butyl alcohol</b>				
17.8±2	25	Audio		(76, 119)
8.19	117.7 B. P.	Audio		(76)
7.8±5*	19	4	8	(48, 49)
<b>C<sub>4</sub>H<sub>10</sub>O, Isobutyl alcohol; M. P. = -108° (see also Table 6)</b>				
18.7±4†	20	Audio		(2, 91, 110, 183)
2.78	< -150			(2)
30.2	-102			(2)
34.2	-95			(2)
31.7	-80			(2)
27.0	-50			(2)
22.8	-20			(2)
20.5	0			(2)
18.7±4	+ 20			(2, 91, 110, 183)
8.0	18	3	8	(160)
6.2§	18	4	8	(48, 49)
<b>C<sub>4</sub>H<sub>10</sub>O, <i>sec</i>-Butyl alcohol</b>				
15.5	19	Audio		(119)
11.6±2	19	4	8	(48, 49)
<b>C<sub>4</sub>H<sub>10</sub>O, <i>tert</i>-Butyl alcohol</b>				
11.4	19	Audio		(119)
6.6±1¶	19	4	8	(48, 49)
<b>C<sub>4</sub>H<sub>10</sub>O, Ethyl ether; M. P. = -116°</b>				
4.335±5**	20	Audio		(17, 42, 63, 133, 136, 139, 177, 183)
1.650	-186	Audio		(87)
2.3	-180	1.2   2		(38)
1.655	-160	Audio		(87)
3.7	-155	1.2   2		(38)
1.752	-130	Audio		(87)
2.100	-120	Audio		(87)
3.750	-115	Audio		(87)
7.51	-110	Audio		(87)
8.95	-108	Audio		(87)
8.148	-100	Audio		(87)
7.05	-80	Audio		(87)
6.33	-60	Audio		(1, 87)
6.10	-60			(127)
5.72	-40	Audio		(1, 87)
5.53	-40			(127)
5.15	-20	Audio		(1, 87)
5.08	-20			(127)
4.683	0	Audio		(1, 87)
4.68	0			(127)

\*  $k' = 0.45$ .

†  $\delta_{20} = -9.5$ .

§  $k' = 0.47$ .

||  $k' = 0.33$ .

¶  $k' = 0.40$ .

\*\*  $\delta_{20} = -1.9$ ,  $n = 3; 6$  (17, 87, 145, 177, 183).



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>4</sub>H<sub>10</sub>O.—(Continued)</b>				
4.335±5	+ 20	Audio		(17, 42, 63, 133, 136, 139, 177, 183)
4.11	34.54 B. P.	Audio		(76)
3.96	40	Audio		(63, 177)
3.40	80	Audio		(63, 177)
2.90	120	Audio		(63, 177)
2.40	160	Audio		(63, 177)
2.13	180	Audio		(63, 177)
1.93	190	Audio		(63, 177)
1.80	192	Audio		(63, 177)
1.6	194	Audio		(63, 177)
1.54	200	Audio		(63, 177)
1.54	250	Audio		(63, 177)
4.32	20	6	4	(86)
4.351	20	6	5	(87)
4.28±3	20	1	6	(124.1, 127, 161.2)
4.36±2	20	4	8	(49)
3.26	20	7	9	(125)
<b>C<sub>4</sub>H<sub>10</sub>O<sub>3</sub>S, sym.-Diethyl sulfite</b>				
17.6	0	Audio		(191)
15.9	20	Audio		(191)
13.7	50	Audio		(191)
16.0±2	20	4	8	(190)
<b>C<sub>4</sub>H<sub>10</sub>O<sub>3</sub>S, asym.-Diethyl sulfite</b>				
45.7	0	Audio		(191)
41.9	20	Audio		(191)
39.4±8	20	4	8	(190)
<b>C<sub>4</sub>H<sub>10</sub>S, Diethyl sulfide</b>				
7.2	ca. 20	4	8	(9)
<b>C<sub>4</sub>H<sub>10</sub>S<sub>2</sub>, Diethyl disulfide</b>				
15.9±3	19	3.6	8	(54)
<b>C<sub>4</sub>H<sub>11</sub>N, n-Butylamine</b>				
5.4±1	21	3.6	8	(164)
<b>C<sub>4</sub>H<sub>11</sub>N, Diethylamine</b>				
3.7±1	20	3.6	8	(124, 164)
5.5	19	5	8	(41)
<b>C<sub>4</sub>H<sub>11</sub>N, Isobutylamine</b>				
4.52±8	21	3.6	8	(164)
<b>C<sub>4</sub>H<sub>12</sub>O<sub>4</sub>Si, Tetramethyl silicate</b>				
6.0	ca. 20	3.6	8	(124)
<b>C<sub>4</sub>H<sub>4</sub>O<sub>2</sub>, Furfuraldehyde</b>				
47.2	0	Audio		(191)
41.9	20	Audio		(191)
34.9	50	Audio		(191)
39±2	20	4	8	(49, 190)
<b>C<sub>4</sub>H<sub>4</sub>O<sub>3</sub>, Citraconic anhydride</b>				
40.3±8	20	4	8	(189)
<b>C<sub>5</sub>H<sub>5</sub>N, Pyridine</b>				
12.5	20	Audio		(28, 76)
11.4	50	Audio		(28)
10.6	80	Audio		(28)
9.38	115.5 B. P.	Audio		(28, 76)
12.5	20	6.7	7	(193.1)
12.4±2	20	4	8	(41, 99, 124, 163)
<b>C<sub>5</sub>H<sub>7</sub>NO<sub>2</sub>, Ethyl cyanoacetate</b>				
27.7	21	Audio		(191)
27.0±3*	20	4	8	(49, 189)

\*  $k' = 0.06$ .

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>5</sub>H<sub>7</sub>NO<sub>2</sub>, 1-Cyanoethyl acetate</b>				
19.3±4	20	4	8	(189)
<b>C<sub>5</sub>H<sub>8</sub>O<sub>3</sub>, Acetylacetone</b>				
26.0	0	Audio		(191)
23.1	20	Audio		(191)
25.9±5	20	4	8	(49, 54, 189)
<b>C<sub>5</sub>H<sub>8</sub>O<sub>4</sub>, Dimethyl malonate</b>				
10.4±2	20	4	8	(41, 189)
<b>C<sub>5</sub>H<sub>8</sub>BrO<sub>2</sub>, 1-Bromoisovaleric acid</b>				
6.5	20	5	8	(41)
<b>C<sub>5</sub>H<sub>8</sub>BrO<sub>2</sub>, Ethyl 1-bromopropionate</b>				
10.1	0	Audio		(191)
9.4	20	Audio		(191)
8.9±2	20	5	8	(41)
<b>C<sub>5</sub>H<sub>8</sub>ClO<sub>2</sub>, Ethyl 1-chloropropionate</b>				
10.1	20	5	8	(41)
<b>C<sub>5</sub>H<sub>8</sub>ClO<sub>2</sub>, Isobutyl chloroformate</b>				
9.2	20	5	8	(41)
<b>C<sub>5</sub>H<sub>8</sub>IO<sub>2</sub>, Ethyl 2-iodopropionate</b>				
8.8±2	20	5	8	(41)
<b>C<sub>5</sub>H<sub>7</sub>N, n-Valeronitrile; slight absorption</b>				
17.7±3	21	3.6	8	(163)
<b>C<sub>5</sub>H<sub>7</sub>N, Isobutyl cyanide; slight absorption</b>				
18.3±4	22	3.6	8	(163)
<b>C<sub>5</sub>H<sub>10</sub>, Amylene</b>				
2.23	16	Audio		(110)
2.07	21	Audio		(42)
6.9(?)	22	3.6	8	(124)
<b>C<sub>5</sub>H<sub>10</sub>Br<sub>2</sub>, Amylene bromide</b>				
5.64±5	15	Audio		(91)
<b>C<sub>5</sub>H<sub>10</sub>O, Valeraldehyde</b>				
11.8	15	2.5	7	(181)
10.3	17	4	8	(49)
<b>C<sub>5</sub>H<sub>10</sub>O, Diethyl ketone</b>				
17.3	15	4	8	(49)
<b>C<sub>5</sub>H<sub>10</sub>O, Methyl propyl ketone</b>				
16.8	15	2.5	7	(181)
15.4	17	4	8	(49)
<b>C<sub>5</sub>H<sub>10</sub>O<sub>2</sub>, Valeric acid</b>				
2.68	17	Audio		(91)
2.68±5	18	4	8	(41, 49)
<b>C<sub>5</sub>H<sub>10</sub>O<sub>2</sub>, Isovaleric acid</b>				
2.79±5	20	4	8	(49)
<b>C<sub>5</sub>H<sub>10</sub>O<sub>2</sub>, n-Butyl formate</b>				
2.43	-194.3	4.7	5	(89)
<b>C<sub>5</sub>H<sub>10</sub>O<sub>2</sub>, Ethyl propionate</b>				
5.76±0.1	20	Audio		(119, 180)
5.76±0.1	20	4	8	(49)
5.0	20	5	8	(41)
<b>C<sub>5</sub>H<sub>10</sub>O<sub>2</sub>, Isobutyl formate</b>				
8.4	13.5	3.8	1	(180)
7.35	23	Audio		(110)
6.5±1	19	4	8	(49)
$k'_{20} = 0.008$		2	8	(35)
<b>C<sub>5</sub>H<sub>10</sub>O<sub>2</sub>, Methyl butyrate</b>				
5.6	20	5	8	(41)
<b>C<sub>5</sub>H<sub>10</sub>O<sub>2</sub>, Propyl acetate</b>				
6.3±3*	20	Audio		(110, 119, 180)
5.8±1	+ 19	4	8	(49)
2.42	-192	4.7	5	(89)
<b>C<sub>5</sub>H<sub>10</sub>O<sub>3</sub>, Ethyl carbonate</b>				
3.15±6	20	4	8	(49, 124)

\*  $\partial_{20} = -0.8$ .



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>5</sub>H<sub>11</sub>Br, Amyl bromide</b>				
6.3±1	10	Audio		(91)
<b>C<sub>5</sub>H<sub>11</sub>Br, Isoamyl bromide</b>				
6.1	25	Audio		(76)
4.70	120.6 B. P.	Audio		(76)
6.1	18	5	8	(41)
<b>C<sub>5</sub>H<sub>11</sub>Br, <i>tert</i>-Amyl bromide</b>				
9.1	18.5	5	8	(41)
<b>C<sub>5</sub>H<sub>11</sub>Cl, Amyl chloride</b>				
6.6±1	11	Audio		(91)
<b>C<sub>5</sub>H<sub>11</sub>Cl, Isoamyl chloride</b>				
6.4±1	18	5	8	(41)
<b>C<sub>5</sub>H<sub>11</sub>Cl, <i>tert</i>-Amyl chloride</b>				
9.5±1	16	Audio		(91)
7.1	18	5	8	(41)
<b>C<sub>5</sub>H<sub>11</sub>I, Isoamyl iodide</b>				
5.6	18.6	5	8	(41)
<b>C<sub>5</sub>H<sub>11</sub>I, <i>tert</i>-Amyl iodide</b>				
6.9	17.3	5	8	(41)
<b>C<sub>5</sub>H<sub>11</sub>N, Piperidine</b>				
5.9±1	20	3.6	8	(164)
<b>C<sub>5</sub>H<sub>11</sub>NO, Methyl propyl ketoxime</b>				
3.3	20	5	8	(41)
<b>C<sub>5</sub>H<sub>11</sub>NO<sub>3</sub>, Amyl nitrate</b>				
9.1±2	18	3.6	8	(124)
<b>C<sub>5</sub>H<sub>12</sub>, Pentane</b>				
1.828	20.3	Audio		(42)
<b>C<sub>5</sub>H<sub>12</sub>O, Amyl alcohol; M. P. = -78.5° (see also Table 6)</b>				
15.8±2*	20	Audio		(2, 91, 110, 133, 145)
2.40	-189			(38)
2.14	-187			(38)
2.6	-160			(38)
6.5	-140			(38)
12.0	-136			(38)
26.5	-132			(38)
34.4	-130			(38)
43.0	-126			(38)
41.0	-117	1.2	2	(38)
35.5	-117	Audio		(1, 2)
29.1	-80			(1, 2)
24.8	-50			(1, 2)
20.9	-20			(1, 2)
18.3	0			(145)
15.8±3	+20			(2, 91, 110, 133, 145)
11.3	60			(145)
14.6	15	2.5	7	(181)
<b>C<sub>5</sub>H<sub>12</sub>O, Dimethyl ethyl carbinol</b>				
11.7	20	Audio		(28)
10.1	50	Audio		(28)
8.9	80	Audio		(28)
8.0	102 B. P.	Audio		(28)
<b>C<sub>5</sub>H<sub>12</sub>O, Isoamyl alcohol</b>				
15.3	23	Audio		(76)
8.87	80	Audio		(28)
5.82	131.6 B. P.	Audio		(28, 76)
5.7	18	3	8	(160)
<b>C<sub>5</sub>H<sub>12</sub>S, Amylmercaptan</b>				
4.7	20	3.6	8	(54, 163)
4.3	30	3.6	8	(54)
<b>C<sub>5</sub>H<sub>13</sub>N, Amylamine</b>				
4.6±1	22	3.6	8	(164)

\*  $\partial_{20} = -12$  (1, 2, 145).

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>6</sub>H<sub>5</sub>N<sub>3</sub>O<sub>6</sub>, 1, 3, 5-Trinitrobenzene</b>				
7.21	127	Audio		(9)
2.2	ca. 20	4	8	(9)
<b>C<sub>6</sub>H<sub>4</sub>Br<sub>2</sub>, <i>m</i>-Dibromobenzene</b>				
8.81	20	Audio		(9)
4.4	ca. 20	4	8	(9)
<b>C<sub>6</sub>H<sub>4</sub>Br<sub>2</sub>, <i>p</i>-Dibromobenzene</b>				
4.57	88	Audio		(9)
2.78		4	8	(9)
<b>C<sub>6</sub>H<sub>4</sub>Cl<sub>2</sub>, <i>o</i>-Dichlorobenzene</b>				
7.47	25	1	6	(161.2)
7.50	20	6.7	7	(193.1)
<b>C<sub>6</sub>H<sub>4</sub>Cl<sub>2</sub>, <i>p</i>-Dichlorobenzene; M. P. = 52.1°</b>				
2.86	53	Audio		(28)
<b>C<sub>6</sub>H<sub>3</sub>N<sub>2</sub>O<sub>4</sub>, <i>m</i>-Dinitrobenzene</b>				
20.7	90	Audio		(9)
2.85	ca. 20	4	8	(9)
<b>C<sub>6</sub>H<sub>5</sub>Br, Bromobenzene</b>				
5.40±0.1	20	Audio		(17, 42, 91, 191)
5.47	13	6.7	7	(193.1)
5.4±2	20	4	8	(9, 41)
$\partial_{20} = -1.6$				
<b>C<sub>6</sub>H<sub>5</sub>Cl, Chlorobenzene</b>				
5.94	20	Audio		(17, 42)
4.70	100	Audio		(17)
4.20	132.0 B. P.	Audio		(76)
5.44	25	1	6	(161.2)
5.65	13	6.7	7	(193.1)
5.8	20	5	8	(41)
$\partial_{20} = -2.4$				
<b>C<sub>6</sub>H<sub>5</sub>ClO, <i>o</i>-Chlorophenol</b>				
8.2	19	5	8	(9)
6.31	25	1	6	(161.2)
<b>C<sub>6</sub>H<sub>5</sub>I, Iodobenzene</b>				
4.6	20	5	8	(41)
<b>C<sub>6</sub>H<sub>5</sub>NO<sub>2</sub>, Nitrobenzene; M. P. = +8.7°</b>				
36.1±3*	20	Audio		(2, 119, 183, 191)
2.62	-190			(68)
2.54	-170			(68)
2.56	-150			(68)
2.63	-100			(68)
2.97	-80			(68)
3.15	-40			(68)
3.40	-20			(68)
9.9	-10			(2)
42.1	-9			(2)
39.7	0			(2)
36.1±3	+20			(2, 119, 183, 191)
32.3	40			(92)
26.3	80			(92)
27.0	80			(127)
21.9	120			(92)
18.6	160			(92)
15.9	200			(92)
15.61	210.85 B. P.	Audio		(76)
35.4	20	6	5	(92)
34.3±6	20	4	8	(49, 99, 190)
37.5	20	5	8	(41)

\*  $\partial_{20} = -18$  (2, 183, 191).



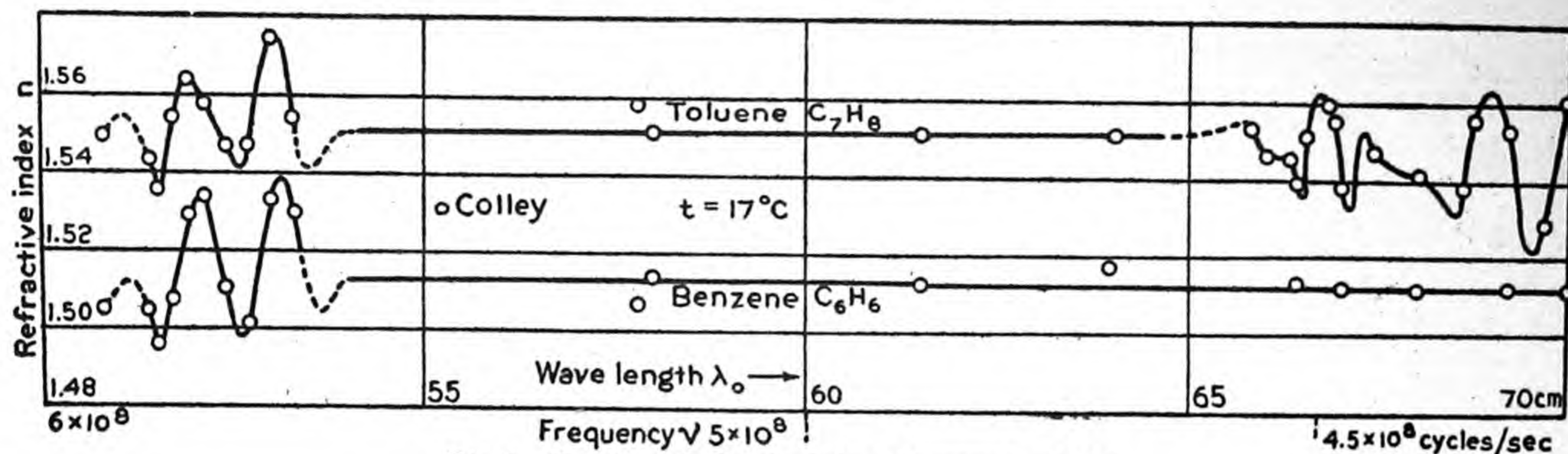


FIG. 1.—Variation of refractive index with wave-length (34).

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>6</sub>H<sub>6</sub>, Benzene; M. P. = 5.5° (see Fig. 1)</b>				
2.283±2*	20	Audio		(177, 183, 188)
2.293	-180			(87)
2.310	-120			(87)
2.322	-80			(87)
2.337	-40			(87)
2.340	-20			(87)
2.342	-10			(87)
2.363	+3			(87)
2.345	4			(87)
2.308	5			(75)
2.300	10			(75, 87)
2.296±1	10			(77, 127)
2.282	20			(34, 75, 87, 177, 183, 188)
2.204	60			(75, 87, 177)
2.228±2	60			(77, 127)
2.127	100			(177)
2.049	140			(177)
1.970	180			(177)
2.28	20	6	5	(75)
2.28	20	1; 3	7	(123)
2.281±4	20	4	8	(34, 49, 117)
2.43	19	6	8	(122)
2.57	19	8	8	(122)
2.26	ca. 20	3	9	(108)
3.4(?)	ca. 20	3.5	9	(111)
2.31	ca. 20	4.7	9	(108)
2.33(?)	ca. 20	7	9	(108)
3.83(?)	ca. 20	7	9	(122)
3.13	ca. 20	3.7	10	(109)
3.1	ca. 20	5	10	(109)
3.04	ca. 20	7.5	10	(109)
<b>C<sub>6</sub>H<sub>5</sub>BrN, <i>m</i>-Bromoaniline</b>				
13.0	19	5	8	(41)
<b>C<sub>6</sub>H<sub>5</sub>ClN, <i>m</i>-Chloroaniline</b>				
13.3±2	16	Audio		(91)
13.3	19	5	8	(41)
<b>C<sub>6</sub>H<sub>5</sub>O, Phenol; M. P. = +41°</b>				
ca. 15	40	Audio		(140)
2.54	-185			(38)
2.59	-140			(38)
4.33	+10	4	8	(49)
9.9±2	48	4	8	(49)

\*  $\delta_{20} = -0.19$  (75, 77, 87, 127, 149).

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>6</sub>H<sub>5</sub>O<sub>2</sub>, Resorcinol</b>				
3.2±28	22	4	8	(174)
<b>C<sub>6</sub>H<sub>5</sub>N, Aniline; M. P. = -6.2°</b>				
7.25±5*	20	Audio		(91, 133, 183)
2.92	-178			(38)
2.95	-160			(38)
3.05	-120			(38)
3.48	-80			(38)
7.78	0			(92, 145)
7.25±5	+20			(91, 95, 133, 183)
6.59	50			(145)
6.43	50			(92)
6.22	70			(145)
5.98	70			(92)
5.46	100			(92)
4.71	150			(92)
4.45	170			(92)
4.54	184.5 B. P.			(76)
7.18±7	20	1	6	(95)
7.2±1	20	4	8	(41, 49, 124, 164)
4.36	ca. 20	7	9	(125)
<b>C<sub>6</sub>H<sub>7</sub>N, <math>\alpha</math>-Picoline</b>				
10.0±2	20	3.6	8	(164)
<b>C<sub>6</sub>H<sub>5</sub>N<sub>2</sub>, Phenylhydrazine</b>				
7.15±0.21	23	Audio		(183)
5.8	17	4	8	(41, 124)
<b>C<sub>6</sub>H<sub>5</sub>O<sub>4</sub>, Methyl acetoneoxalate</b>				
15.4†	67	4	8	(49)
2.38†	6	4	8	(49)
<b>C<sub>6</sub>H<sub>5</sub>ClO<sub>2</sub>, Ethyl 2-chlorocrotonate</b>				
7.67§	20	4	5	(61.1)
4.70	20	4	5	(61.1)
<b>C<sub>6</sub>H<sub>10</sub>O, Cyclohexanone</b>				
18.2	20	Audio		(147)
<b>C<sub>6</sub>H<sub>10</sub>O, Mesityl oxide</b>				
15.4±3	20	4	8	(189)
<b>C<sub>6</sub>H<sub>10</sub>O<sub>2</sub>, Ethyl crotonate</b>				
5.4±2	20	5	8	(41)

\*  $\delta_{20} = -2.5$  (92, 145, 183).†  $k' = 0.06$ .‡  $k' = 0.06$ .

§ Cis; B. P. = 75.3; 76.0° at pressure of 14 mm Hg.

|| Trans; B. P. = 54.0° at pressure of 14 mm Hg.



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
18.3±6	C <sub>6</sub> H <sub>10</sub> O <sub>3</sub> , Propionic anhydride	16	5	8 (41)
15.9±2	C <sub>6</sub> H <sub>10</sub> O <sub>2</sub> , Ethyl acetoacetate	22	4	8 (49)
8.2±1	C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> , Diethyl oxalate	21	4	8 (49)
5.20	C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> , Dimethyl succinate	19.5 M. P.	Audio	(28)
4.9	C <sub>6</sub> H <sub>10</sub> S, Diallyl sulfide	ca. 20	4	8 (9)
8.0	C <sub>6</sub> H <sub>11</sub> BrO <sub>2</sub> , Ethyl 1-bromobutyrate	20	5	8 (41)
7.9	C <sub>6</sub> H <sub>11</sub> BrO <sub>2</sub> , Ethyl 1-bromoisobutyrate	20	5	8 (41)
7.8	C <sub>6</sub> H <sub>11</sub> ClO <sub>2</sub> , Isoamyl chloroformate	20	5	8 (41)
15.7±2	C <sub>6</sub> H <sub>11</sub> N, Isocaproitrile; slight absorption	20	3.3	8 (99, 163)
17.4±3	C <sub>6</sub> H <sub>11</sub> NS, Amyl thiocyanate	20	3.6	8 (54)
2.052	C <sub>6</sub> H <sub>12</sub> , Cyclohexane	20	Audio	(28, 147)
2.10		4.5 M. P.	Audio	(28)
	$\delta_{20} = -0.16$			(28)
2.03	C <sub>6</sub> H <sub>12</sub> , $\alpha$ -Hexylene	17	Audio	(110)
15.0	C <sub>6</sub> H <sub>12</sub> O, Cyclohexanol	25	Audio	(147)
12.4±2	C <sub>6</sub> H <sub>12</sub> O, Methyl <i>tert</i> .-butyl ketone	17	4	8 (49)
12.8	C <sub>6</sub> H <sub>12</sub> O, Pinacolin	17.5	3.6	8 (54)
3.22±6	C <sub>6</sub> H <sub>12</sub> O <sub>2</sub> , Caproic acid	18	5	8 (41)
7.7	C <sub>6</sub> H <sub>12</sub> O <sub>2</sub> , Amyl formate	15	3.8	1 (180)
5.7		19	4	8 (49)
	$k'_{20} = 0.009$	2	8	(35)
5.14*	C <sub>6</sub> H <sub>12</sub> O <sub>2</sub> , <i>n</i> -Butyl acetate	+ 19	Audio	(119)
2.41		-195		(89)
2.395		-77.9		(89)
6.97		-77.9		(89)
5.54		-20		(89)
5.34		0		(89)
5.00		+ 20		(89)
5.00		20	4.7	5 (89)
5.1±1		19	4	8 (49)
5.19±5	C <sub>6</sub> H <sub>12</sub> O <sub>2</sub> , Ethyl butyrate	20	Audio	(112, 180)
5.2±1		20	4	8 (49)
$\delta_{20} = -1.0$		20	Audio	(119)
5.60±0.1†	C <sub>6</sub> H <sub>12</sub> O <sub>2</sub> , Isobutyl acetate	20	Audio	(110, 119, 180)
5.32		25	1	6 (161.2)
5.4±1		20	4	8 (49)
4.3	C <sub>6</sub> H <sub>12</sub> O <sub>2</sub> , Methyl valerate	19	5	8 (41)
4.7	C <sub>6</sub> H <sub>12</sub> O <sub>2</sub> , Propyl propionate	20	5	8 (41)

\*  $\delta_{20} = -1.6$  (89, 119).†  $\delta_{20} = -1.6$  (119).

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
14.5±1	C <sub>6</sub> H <sub>12</sub> O <sub>3</sub> , Paraldehyde	20	Audio	(76, 191)
12.2±2		50	Audio	(191)
6.29		128.0 B. P.	Audio	(76)
ca. 12.0		20	4	8 (189)
6.6	C <sub>6</sub> H <sub>13</sub> I, Hexyl iodide	20	5	8 (41)
1.874*	C <sub>6</sub> H <sub>14</sub> , Hexane	20	Audio	(110, 133, 147, 188)
3.45±5	C <sub>6</sub> H <sub>14</sub> O <sub>2</sub> , Acetal	24	Audio	(191)
3.59±9		21	4	8 (49)
7.4	C <sub>6</sub> H <sub>14</sub> O <sub>2</sub> , Pinacone	24	3.6	8 (124)
3.0±28	C <sub>6</sub> H <sub>14</sub> O <sub>6</sub> , Mannitol	22	4	8 (174)
2.9	C <sub>6</sub> H <sub>15</sub> N, Dipropylamine	20	3.6	8 (124, 164)
3.15	C <sub>6</sub> H <sub>15</sub> N, Triethylamine	21	Audio	(191)
19.0±4	C <sub>7</sub> H <sub>5</sub> ClO, Benzoyl chloride	24	3.6	8 (124)
7.4	C <sub>7</sub> H <sub>5</sub> Cl <sub>3</sub> , Benzotrichloride	20	3.6	8 (124)
6.4		20	5	8 (41)
26.5	C <sub>7</sub> H <sub>5</sub> N, Benzonitrile	20	Audio	(191)
28.8		0	Audio	(191)
26.5		20	4	8 (49, 163, 190)
5.7	C <sub>7</sub> H <sub>5</sub> NO, Phenyl isocyanate	17	3.6	8 (54)
8.9		20	3.6	8 (124)
10.7±5	C <sub>7</sub> H <sub>5</sub> NS, Phenyl isothiocyanate	20	4	8 (124, 189)
6.9	C <sub>7</sub> H <sub>5</sub> Cl <sub>2</sub> , Benzal chloride	20	5	8 (41)
48.1	C <sub>7</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub> , <i>anti-m</i> -Nitrobenzaloxime	120	Audio	(9)
2.58			4	8 (9)
59.3	C <sub>7</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub> , <i>syn-m</i> -Nitrobenzaloxime	117.5	Audio	(9)
2.78			4	8 (9)
18.0	C <sub>7</sub> H <sub>5</sub> O, Benzaldehyde	20	Audio	(191)
20.0		0	Audio	(191)
17.5±3		20	4	8 (49)
14.5		15	2.5	7 (181)
14.1±3		20	3.6	8 (124)
13.9	C <sub>7</sub> H <sub>5</sub> O <sub>2</sub> , Salicylaldehyde	20	4	8 (189)
17.9		17	4	8 (49)
19.2		15	2.5	7 (181)
5.32	C <sub>7</sub> H <sub>7</sub> Br, <i>o</i> -Bromotoluene	20	5	8 (41)
5.15	C <sub>7</sub> H <sub>7</sub> Br, <i>p</i> -Bromotoluene	28 M. P.	Audio	(28)
7.0±2	C <sub>7</sub> H <sub>7</sub> Cl, Benzyl chloride	13	Audio	(91)
6.4		20	5	8 (41)
4.72	C <sub>7</sub> H <sub>7</sub> Cl, <i>o</i> -Chlorotoluene	20	5	8 (41)

\*  $\delta_{20} = -0.11$ ;  $(-80 t + 12)$  (127).



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b><math>C_7H_7Cl</math>, <i>m</i>-Chlorotoluene</b>				
5.4	16	Audio		(91)
5.55	20	5	8	(41)
<b><math>C_7H_7Cl</math>, <i>p</i>-Chlorotoluene</b>				
6.40	10	Audio*		(28)
6.19	20	Audio		(28)
5.94	30	Audio		(28)
6.45	7.4 M. P.			(28)
6.21	20	5	8	(41)
<b><math>C_7H_7I</math>, <i>p</i>-Iodotoluene</b>				
4.46	35 M. P.	Audio		(28)
<b><math>C_7H_7NO</math>, <i>anti</i>-Benzaldoxime</b>				
3.85±4	20	Audio		(119)
3.40±6	20	4	8	(49)
3.55	20	5	8	(41)
<b><math>C_7H_7NO</math>, Formanilide</b>				
20.57				(189)
3.058		4	8	(9)
<b><math>C_7H_7NO_2</math>, <i>o</i>-Nitrotoluene</b>				
27.42±5*	20	Audio		(183)
25.8	20	2.5	7	(181)
20.3	18	3.6	8	(124)
26.0	20	5	8	(41)
11.82	222.3 B. P.	Audio		(76)
<b><math>C_7H_7NO_2</math>, <i>m</i>-Nitrotoluene</b>				
23.8	20	6.7	7	(193.1)
23.6	20	5	8	(41)
<b><math>C_7H_7NO_2</math>, <i>p</i>-Nitrotoluene</b>				
18.7	52 M. P.	Audio		(28)
<b><math>C_7H_7NO_2</math>, <i>m</i>-Nitrobenzyl alcohol</b>				
22.0±5	20	5	8	(41)
<b><math>C_7H_7NO_2</math>, Nitroanisole</b>				
24.2	20	3.6	8	(54)
<b><math>C_7H_8</math>, Toluene; M. P. = -94.5° (see Fig. 1)</b>				
2.387±5†	20	Audio		(17, 42, 110, 145, 177, 111.1)
2.520	-186			(87)
2.526	-140			(87)
2.530	-114			(87)
2.600	-100			(87)
2.632	-94			(87)
2.61	-80			(87)
2.57	-60			(87)
2.485	-20			(17, 87)
2.435	0			(17, 87)
2.387±5	+20			(17, 42, 110, 145, 177)
2.250	80			(87, 177)
2.165	120			(87, 177)
2.040	180			(87, 177)
2.39	20	6	4	(86)
2.388	20	6	5	(87)
2.37±4	20	2.5	7	(181)
2.402±4	20	5	8	(34, 41, 117)
<b><math>C_7H_8O</math>, Benzyl alcohol</b>				
15.9	0	Audio		(191)
13.0	20	Audio		(191)
10.8	50	Audio		(191)
10.8±2‡	21	4	8	(48)

\*  $\partial_{20} = -15$  (183).†  $\partial_{20} = -0.23$  (87, 145, 177).‡  $k' = 0.20$ .

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b><math>C_7H_8O</math>, <i>o</i>-Cresol</b>				
ca. 8	40	Audio		(140)
5.8±1	24	3.6	8	(124)
<b><math>C_7H_8O</math>, <i>m</i>-Cresol</b>				
ca. 13	40	Audio		(140)
5.0±1	24	3.6	8	(124)
<b><math>C_7H_8O</math>, <i>p</i>-Cresol</b>				
ca. 13	40	Audio		(140)
5.6±1	24	3.6	8	(124)
<b><math>C_7H_8O</math>, Anisole</b>				
4.7	5	Audio		(191)
4.35±5	20	Audio		(140, 191)
4.0	50	Audio		(191)
3.62±7	18	3.6	8	(124)
<b><math>C_7H_8O_2</math>, Guaiacol (supercooled)</b>				
11.77	<32	5	8	(41)
<b><math>C_7H_9N</math>, Benzylamine</b>				
5.6	0	Audio		(191)
4.6	20	Audio		(191)
4.3	50	Audio		(191)
5.2	20	5	8	(41)
<b><math>C_7H_9N</math>, Methylaniline</b>				
7.98	0	Audio		(191)
6.01	20	Audio		(191)
5.9	20	3.6	8	(124, 164)
<b><math>C_7H_9N</math>, <i>o</i>-Toluidine</b>				
6.4	26	Audio		(76)
4.00	199.7 B. P.	Audio		(76)
6.0	20	4	8	(41, 164)
<b><math>C_7H_9N</math>, <i>m</i>-Toluidine</b>				
6.0	20	4	8	(41, 164)
<b><math>C_7H_9N</math>, <i>p</i>-Toluidine; M. P. = 43.7°</b>				
5.48	44	Audio		(28)
3.0±2	22	4	8	(174)
<b><math>C_7H_{10}N_2</math>, <i>asym.</i>-Methylphenylhydrazine</b>				
7.3	19	5	8	(41)
<b><math>C_7H_{10}O</math>, 1-Methyl-5-ketocyclohexylene</b>				
24.32	20			(154)
<b><math>C_7H_{10}O_4</math>, Ethyl acetoneoxalate</b>				
16±1	19	Audio		(119)
16.7±3*	19	4	8	(49)
<b><math>C_7H_{10}O_4</math>, Ethyl hydroxymethyleneacetoacetate</b>				
8.12	21	Audio		(119)
7.8±1†	21	4	8	(49)
<b><math>C_7H_{12}O_2</math>, Ethyl levulinate</b>				
12.1±2	21	4	8	(49)
<b><math>C_7H_{12}O_4</math>, Diethyl malonate</b>				
7.9±2	21	4	8	(49)
8.4±2	21	5	8	(41)
<b><math>C_7H_{13}ClO_2</math>, Isoamyl chloroacetate</b>				
7.8	20	5	8	(41)
<b><math>C_7H_{14}O</math>, Dipropyl ketone</b>				
12.6±2	17	1; 40	7	(49, 181)
<b><math>C_7H_{14}O_2</math>, Amyl acetate</b>				
5.07±9‡	20	Audio		(110, 119, 180)
4.62	25	1	6	(161.2)
4.88±0.1	20	4	8	(49)
<b><math>C_7H_{14}O_2</math>, Ethyl valerate</b>				
4.81§	20	Audio		(119, 180)
4.77±9	20	4	8	(49)

\*  $k' = 0.09$ . †  $k' = 0.08$ . ‡  $\partial_{20} = -1.2$  (119). §  $\partial_{20} = -1.0$  (119).



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>7</sub>H<sub>14</sub>O<sub>2</sub>, Propyl butyrate</b>				
4.3	20	5	8	(41)
<b>C<sub>7</sub>H<sub>16</sub>, Heptane</b>				
1.971	20	Audio		(42, 147)
<b>C<sub>7</sub>H<sub>16</sub>O, Heptyl alcohol</b>				
6.73	21	Audio		(119)
4.2±1*	21	4	8	(49)
<b>C<sub>7</sub>H<sub>16</sub>O, Ethyl amyl ether</b>				
3.565	23	Audio		(42)
4.02	20	5	8	(41)
<b>C<sub>8</sub>H<sub>6</sub>O<sub>2</sub>, Phthalide</b>				
36	75	4	8	(49)
48	20	4	8	(49)
<b>C<sub>8</sub>H<sub>7</sub>N, Benzyl cyanide</b>				
20.10	0	Audio		(191)
18.32	20	Audio		(191)
16.84	50	Audio		(191)
8.5	233.5 B. P.	Audio		(76)
15.2	20	4	8	(49, 163)
16.7	20	4	8	(189)
<b>C<sub>8</sub>H<sub>7</sub>N, <i>o</i>-Tolunitrile</b>				
18.8±4	23	3.6	8	(163)
<b>C<sub>8</sub>H<sub>7</sub>NO, Mandelic nitrile</b>				
18.1±3†	23	3.6	8	(164)
<b>C<sub>8</sub>H<sub>8</sub>O, Phenylacetaldehyde</b>				
4.87±9	20	4	8	(49)
<b>C<sub>8</sub>H<sub>8</sub>O, Acetophenone</b>				
18.6±1	15	Audio		(191)
18.8±1	20	Audio		(183, 191)
15.9±2	50	Audio		(191)
8.64	202.0 B. P.	Audio		(76)
16.2	15	2.5	7	(181)
15.8±8	20	4	8	(49)
<b>C<sub>8</sub>H<sub>8</sub>O<sub>2</sub>, <i>p</i>-Anisaldehyde</b>				
10.38	248.0 B. P.	Audio		(76)
ca. 22.3	22	Audio		(76)
ca. 15.8	20	4	8	(189)
<b>C<sub>8</sub>H<sub>8</sub>O<sub>2</sub>, Phenylacetic acid</b>				
ca. 4	85	4	8	(49)
ca. 3.2	20	4	8	(49)
<b>C<sub>8</sub>H<sub>8</sub>O<sub>2</sub>, Methyl benzoate</b>				
6.9±2‡	20	Audio		(119, 180)
6.6±2	20	4	8	(49, 124)
<b>C<sub>8</sub>H<sub>8</sub>O<sub>2</sub>, Phenyl acetate</b>				
5.35±5§	20	Audio		(119)
5.15	25	1	6	(161.2)
5.38±0.1	20	4	8	(49)
6.4	24	3.6	8	(124)
$k' = 0.012$	20	2	8	(35)
<b>C<sub>8</sub>H<sub>8</sub>O<sub>3</sub>, Methyl salicylate</b>				
9.0±2	20	4	8	(41, 49)
<b>C<sub>8</sub>H<sub>9</sub>NO, Acetanilide</b>				
19.5l				(189)
2.9±18	22			(9, 174)
<b>C<sub>8</sub>H<sub>9</sub>NO<sub>2</sub>, <i>anti-p</i>-Anisaldoxime</b>				
9.28	63	Audio		(9)
2.78		4	8	(9)

\*  $k' = 0.31$ .†  $k' = 0.045$ .‡  $\partial_{20} = -1.2$  (119, 180).§  $\partial_{20} = -0.75$  (119).||  $k' = 0.07$ .

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>8</sub>H<sub>9</sub>NO<sub>2</sub>, <i>syn-p</i>-Anisaldoxime</b>				
10.9	130	Audio		(9)
2.78		4	8	(9)
<b>C<sub>8</sub>H<sub>10</sub>, Ethylbenzene</b>				
2.479	20	Audio		(110, 133, 147)
<b>C<sub>8</sub>H<sub>10</sub>, <i>o</i>-Xylene</b>				
2.58	17	Audio		(110, 133)
2.58±5	17	4	8	(41, 49)
<b>C<sub>8</sub>H<sub>10</sub>, <i>m</i>-Xylene; M. P. = -53.6°</b>				
2.374±2*	+ 20	Audio		(42, 133, 147, 177, 183)
2.400	-186			(87)
2.550†	-80			(87)
2.400	-70			(87)
2.600‡	-60			(87)
2.458	-52			(87)
2.530	-50			(87)
2.566	-48			(87)
2.540	-40			(87)
2.473	-20			(87)
2.420	0			(87)
2.374	+ 20			(42, 133, 147, 177, 183)
2.257	80			(177)
2.178	120			(177)
2.058	180			(177)
2.392	20	6	5	(87)
2.35	20	5	7	(8)
2.37±3	20	4	8	(49)
<b>C<sub>8</sub>H<sub>10</sub>, <i>p</i>-Xylene</b>				
2.259	17	Audio		(110, 133)
2.21	17	4	8	(41, 49)
<b>C<sub>8</sub>H<sub>10</sub>O, <i>o</i>-Tolyl methyl ether</b>				
3.57	20	Audio		(140)
3.4±1	20	4	8	(41, 124)
<b>C<sub>8</sub>H<sub>10</sub>O, <i>m</i>-Tolyl methyl ether</b>				
4.08	20	Audio		(140)
3.6	20	5	8	(41)
<b>C<sub>8</sub>H<sub>10</sub>O, <i>p</i>-Tolyl methyl ether</b>				
4.03	20	Audio		(140)
3.6	20	5	8	(41)
<b>C<sub>8</sub>H<sub>10</sub>O, Phenetole</b>				
4.56±9	21	3.6	8	(124)
<b>C<sub>8</sub>H<sub>10</sub>O, 1, 3, 4-Xylenol</b>				
4.8	17	5	8	(41)
<b>C<sub>8</sub>H<sub>10</sub>O<sub>2</sub>, Creosol</b>				
10.6	17	Audio		(119)
11.8	15	2.5	7	(181)
6‡	17	4	8	(49)
<b>C<sub>8</sub>H<sub>10</sub>O<sub>2</sub>, Veratrol</b>				
4.54	22.5 M. P.	Audio		(28)
<b>C<sub>8</sub>H<sub>11</sub>N, Benzylmethylaniline</b>				
4.4	19	5	8	(41)
<b>C<sub>8</sub>H<sub>11</sub>N, Dimethylaniline</b>				
4.84	0	Audio		(191)
4.48	20	Audio		(191)
3.93	50	Audio		(191)
5.1	20	3.6	8	(124, 164)

\*  $\partial_{20} = -0.10 \pm 1$  (87, 133, 177, 183).

† Supercooled.

‡  $k' = 0.28$ .



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>8</sub>H<sub>11</sub>N, Ethylaniline</b>				
6.3	0	Audio		(191)
5.9	20	Audio		(191)
5.76	20	6.7	7	(193.1)
5.4	19	5	8	(41)
<b>C<sub>8</sub>H<sub>11</sub>N, <i>m</i>-Xylidine</b>				
5.0±1	20	4	8	(41, 124, 164)
<b>C<sub>8</sub>H<sub>11</sub>NO, Phenetidine</b>				
7.3±2	21	3.6	8	(124)
<b>C<sub>8</sub>H<sub>12</sub>O<sub>5</sub>, Diethyl oxaloacetate</b>				
6.1±1*	19	4	8	(49)
<b>C<sub>8</sub>H<sub>12</sub>O<sub>5</sub>, Ethyl hydroxymethylenemalonate</b>				
6.6±1†	22	4	8	(49)
<b>C<sub>8</sub>H<sub>14</sub>O<sub>3</sub>, Butyric anhydride</b>				
12.9	20	5	8	(41)
<b>C<sub>8</sub>H<sub>14</sub>O<sub>3</sub>, Isobutyric anhydride</b>				
13.9±3	20	4	8	(189)
17.8	17	5	8	(41)
<b>C<sub>8</sub>H<sub>14</sub>O<sub>5</sub>, Diethyl <i>dl</i>-malate</b>				
10.2±2‡	18	4	8	(49)
<b>C<sub>8</sub>H<sub>14</sub>O<sub>5</sub>, Diethyl <i>l</i>-malate</b>				
9.5±2	20	4	8	(189)
<b>C<sub>8</sub>H<sub>14</sub>O<sub>6</sub>, Diethyl tartrate</b>				
4.59±9	20	5	8	(176)
<b>C<sub>8</sub>H<sub>14</sub>O<sub>6</sub>, Diethyl racemate</b>				
4.59±9	20	5	8	(176)
<b>C<sub>8</sub>H<sub>16</sub>, Octylene</b>				
2.21	12	Audio		(110)
4.15	18.5	5	8	(41)
<b>C<sub>8</sub>H<sub>16</sub>O, Methyl hexyl ketone</b>				
10.4	15	2.5	7	(181)
10.7±2	17	4	8	(49)
<b>C<sub>8</sub>H<sub>16</sub>O<sub>2</sub>, Caprylic acid</b>				
3.26	18.3	5	8	(41)
<b>C<sub>8</sub>H<sub>16</sub>O<sub>2</sub>, Isoamyl propionate</b>				
4.25	19.5	5	8	(41)
<b>C<sub>8</sub>H<sub>16</sub>O<sub>2</sub>, Isobutyl butyrate</b>				
4.05	20	5	8	(41)
<b>C<sub>8</sub>H<sub>16</sub>O<sub>2</sub>, Propyl valerate</b>				
4.00	18.8	5	8	(41)
<b>C<sub>8</sub>H<sub>17</sub>I, <i>n</i>-Octyl iodide</b>				
4.92	20	5	8	(41)
<b>C<sub>8</sub>H<sub>17</sub>I, <i>sec.</i>-Octyl iodide</b>				
5.87	20	5	8	(41)
<b>C<sub>8</sub>H<sub>18</sub>, Octane</b>				
1.960	20	Audio		(110, 133, 147)
<b>C<sub>8</sub>H<sub>18</sub>, 2, 2, 3-Trimethylpentane</b>				
1.959	20	Audio		(147)
<b>C<sub>8</sub>H<sub>18</sub>O, Octyl alcohol</b>				
3.4	18	3	8	(160)
<b>C<sub>8</sub>H<sub>19</sub>N, Diisobutylamine</b>				
2.70±5	22	3.6	8	(164)
<b>C<sub>8</sub>H<sub>20</sub>O<sub>4</sub>Si, Tetraethyl silicate</b>				
4.10	ca. 20	3.6	8	(124)
<b>C<sub>8</sub>H<sub>7</sub>N, Quinoline; M. P. = -22.6°</b>				
9.00	+ 25	Audio		(76, 183)
2.67	-180			(38)
2.9	-150			(38)
11.7	-100			(38)
9.0	+ 25	Audio		(41, 76, 124, 163, 183)

\*  $k' = 0.25$ .†  $k' = 0.09$ .‡  $k' = 0.25$ .

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>9</sub>H<sub>7</sub>N.—(Continued)</b>				
5.05	238 B. P.	Audio		(76)
8.9±1	21	4	8	(41, 124, 163)
<b>C<sub>9</sub>H<sub>7</sub>NO, Hydroxymethylenebenzyl cyanide</b>				
5(?)*	180	4	8	(49)
6(?) <sub>s</sub>	20	4	8	(49)
<b>C<sub>9</sub>H<sub>10</sub>O<sub>2</sub>, Benzyl acetate</b>				
5.05	21.2	5	8	(41)
<b>C<sub>9</sub>H<sub>10</sub>O<sub>2</sub>, Ethyl benzoate</b>				
6.2±1†	20	Audio		(119, 180)
6.0±2	20	4	8	(49, 124)
$k' = 0.018$	20	2	8	(35)
<b>C<sub>9</sub>H<sub>10</sub>O<sub>2</sub>, Methyl <i>p</i>-toluate</b>				
4.34	33	Audio		(28)
<b>C<sub>9</sub>H<sub>10</sub>O<sub>3</sub>, Ethyl salicylate</b>				
8.6	21	Audio		(119)
8.4±2‡	21	4	8	(41, 49)
<b>C<sub>9</sub>H<sub>10</sub>O<sub>3</sub>, Methyl <i>o</i>-methoxybenzoate</b>				
7.8±1‡	21	4	8	(49)
<b>C<sub>9</sub>H<sub>12</sub>, Mesitylene</b>				
2.353	20	Audio		(110, 147)
<b>C<sub>9</sub>H<sub>12</sub>, Cumene</b>				
2.397	20	Audio		(110, 133, 147, 182)
2.42	18	4	8	(49)
<b>C<sub>9</sub>H<sub>12</sub>, Psuedocumene</b>				
2.43	16	Audio		(110, 133)
<b>C<sub>9</sub>H<sub>12</sub>, Propylbenzene</b>				
2.361	20	Audio		(110, 133, 147)
<b>C<sub>9</sub>H<sub>12</sub>O, Ethyl benzyl ether</b>				
3.87±6	20	5	8	(41)
<b>C<sub>9</sub>H<sub>13</sub>N, Benzylethylamine</b>				
4.8	20	5	8	(41)
<b>C<sub>9</sub>H<sub>13</sub>N, <i>o</i>-Dimethyltoluidine</b>				
3.37±7	20	5	8	(41)
<b>C<sub>9</sub>H<sub>13</sub>N, <i>p</i>-Dimethyltoluidine</b>				
3.95±8	20	5	8	(41)
<b>C<sub>9</sub>H<sub>13</sub>NO<sub>3</sub>S, <i>p</i>-Trimethylsulfanilic acid</b>				
ca. 94	12.5	Audio		(101)
ca. 89	18	4	8	(101)
<b>C<sub>9</sub>H<sub>14</sub>O<sub>4</sub>, Diethyl oxalopropionate</b>				
9.1±2§	19	4	8	(49)
<b>C<sub>9</sub>H<sub>14</sub>O<sub>6</sub>, Glyceryl triacetate</b>				
6.0±1	21	5	8	(41)
<b>C<sub>9</sub>H<sub>18</sub>O<sub>2</sub>, Isoamyl butyrate</b>				
3.95±8	20	5	8	(41)
<b>C<sub>9</sub>H<sub>18</sub>O<sub>2</sub>, Isobutyl valerate</b>				
3.85±8	19	5	8	(41)
<b>C<sub>9</sub>H<sub>20</sub>, 2, 2'-Dimethylheptane</b>				
1.89	20	Audio		(147)
<b>C<sub>9</sub>H<sub>20</sub>, 2, 4-Dimethylheptane</b>				
1.89	20	Audio		(147)
<b>C<sub>9</sub>H<sub>20</sub>, 2, 5-Dimethylheptane</b>				
1.99	20	Audio		(147)
<b>C<sub>9</sub>H<sub>20</sub>, 2-Methyloctane</b>				
1.965	20	Audio		(147)
<b>C<sub>9</sub>H<sub>20</sub>, 4-Methyloctane</b>				
1.965	20	Audio		(147)

\*  $k' = 0.30$ .†  $\delta_{20} = -0.9$  (119, 180).‡  $k' = 0.07$ .§  $k' = 0.19$ .



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b><math>C_9H_{20}</math>, Nonane</b>				
1.965	20	Audio		(147)
<b><math>C_{10}H_7Br</math>, 1-Bromonaphthalene</b>				
5.17±5	19	Audio		(183)
5.00±5	22.7	Audio		(42)
4.85±5*	19	4	8	(41, 49)
<b><math>C_{10}H_8</math>, Naphthalene</b>				
2.52±8†	20	4	8	(81, 174)
2.51	15			(81)
2.40	40			(81)
2.30	60			(81)
2.19	80 M. P.			(81)
2.30	100			(81)
2.43	120			(81)
2.61	150			(81)
2.64	180			(81)
2.23	80 M. P.	4	8	(81)
3.27	80.5 M. P.	Audio		(28)
<b><math>C_{10}H_{10}O_2</math>, Benzoylacetone</b>				
15.7(?)‡	80	4	8	(49)
2.8(?)§	20	4	8	(49)
<b><math>C_{10}H_{10}O_2</math>, Safrol</b>				
3.12±6	21	4	8	(49)
2.57	18	3.6	8	(124)
<b><math>C_{10}H_{10}O_2</math>, Isosafrol</b>				
3.40±7	21	4	8	(49)
<b><math>C_{10}H_{12}O</math>, Cumicaldehyde</b>				
10.7	15	2.5	7	(181)
<b><math>C_{10}H_{12}O_2</math>, Phenylethyl acetate</b>				
4.5±2	15	Audio		(171)
<b><math>C_{10}H_{12}O_2</math>, Ethyl phenylacetate</b>				
5.4±1	21	4	8	(49)
<b><math>C_{10}H_{12}O_2</math>, Eugenol; some absorption</b>				
6.1±1	18	3.6	8	(124)
<b><math>C_{10}H_{14}</math>, <i>p</i>-Cymene</b>				
2.26	17	Audio		(76, 110, 133)
2.27	176.5 B. P.	Audio		(76)
2.43	18	3.6	8	(124)
<b><math>C_{10}H_{14}</math>, Isobutylbenzene</b>				
2.36	17	Audio		(110, 133)
<b><math>C_{10}H_{14}</math>, <i>tert.</i>-Butylbenzene</b>				
2.381	20	Audio		(147)
2.0	20	5	8	(41)
<b><math>C_{10}H_{14}O</math>, Carvol</b>				
11.2±2	18	3.6	8	(124)
<b><math>C_{10}H_{14}O_3</math>, "Hagemann's ester"</b>				
18.0±4§	20	4	8	(49)
10.6±2	20	4	8	(49)
<b><math>C_{10}H_{16}</math>, Terpinene</b>				
2.7	21	3.6	8	(124)
<b><math>C_{10}H_{16}</math>, <i>d</i>-Camphene</b>				
2.75	20	5	8	(176)
<b><math>C_{10}H_{16}</math>, <i>l</i>-Camphene</b>				
2.75	20	5	8	(176)
<b><math>C_{10}H_{16}</math>, <i>dl</i>-Camphene</b>				
2.75	20	5	8	(176)
<b><math>C_{10}H_{16}</math>, Dipentene</b>				
2.30	20	5	8	(176)
3.2	21	3.6	8	(124)
<b><math>C_{10}H_{16}</math>, <i>d</i>-Limonene</b>				
2.36	20	5	8	(176)

\*  $k' = 0.05$ .†  $k' = 0.09$ , keto form.‡  $k' = 0.27$ , enol form.†  $\delta_{10} = -0.7$  (81, 174).

‡ Enol form.

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b><math>C_{10}H_{16}</math>, <i>d</i>-Pinene</b>				
2.60	20	5	8	(176)
<b><math>C_{10}H_{16}</math>, <i>l</i>-Pinene</b>				
2.70	20	5	8	(176)
<b><math>C_{10}H_{16}</math>, <i>dl</i>-Pinene</b>				
2.75	20	5	8	(176)
<b><math>C_{10}H_{16}O</math>, Dihydrocarvone</b>				
8.7±2	19	4	8	(49)
<b><math>C_{10}H_{16}O</math>, Carvenone (?)</b>				
19.3±2	20	Audio		(119)
18.4±4*	20	4	8	(49)
<b><math>C_{10}H_{16}O</math>, Pulegone</b>				
9.7±2	19	4	8	(49)
<b><math>C_{10}H_{18}O</math>, Menthone</b>				
9.6	20	5	8	(41)
8.9	18	3.6	8	(124)
<b><math>C_{10}H_{18}O</math>, Terpineol</b>				
3.7	21	3.6	8	(124)
2.80±5	20	4	8	(49)
<b><math>C_{10}H_{18}O_2</math>, Acetylmethyl hexyl ketone</b>				
27.9±5	19	3.6	8	(54)
<b><math>C_{10}H_{20}</math>, Decylene</b>				
2.27	17	Audio		(110)
<b><math>C_{10}H_{20}</math>, Diisoamylene</b>				
2.43	17	Audio		(133)
<b><math>C_{10}H_{20}O_2</math>, Isoamyl valerate</b>				
3.62±7	19	5	8	(41)
<b><math>C_{10}H_{22}</math>, Decane</b>				
1.953	20	Audio		(110, 147)
<b><math>C_{10}H_{22}</math>, Di(iso?)amyl</b>				
1.99	17	Audio		(133)
<b><math>C_{10}H_{22}O</math>, Amyl ether</b>				
3.14±6	16	4	8	(49)
<b><math>C_{10}H_{23}N</math>, Diamylamine</b>				
2.57±5	18	3.6	8	(124)
<b><math>C_{11}H_7N</math>, <math>\alpha</math>-Naphthonitrile</b>				
16.3±3‡	70	3.6	8	(164)
18.4±4‡	40	3.6	8	(164)
19.6±4‡	22	3.6	8	(164)
6.4±1§	21	3.6	8	(164)
<b><math>C_{11}H_7N</math>, <math>\beta</math>-Naphthonitrile</b>				
17.2±3	70	3.6	8	(164)
4.3	22	3.6	8	(164)
<b><math>C_{11}H_{10}O_4</math>, Methyl acetophenoneoxalate; double enol form</b>				
13.2(?)†	70	4	8	(49)
2.8(?)§	18	4	8	(49)
<b><math>C_{11}H_{12}O_2</math>, Ethyl cinnamate</b>				
6.62±6	19	Audio		(119)
5.36±0.1‡	19	4	8	(49)
<b><math>C_{11}H_{12}O_2</math>, Ethyl benzoylacetate</b>				
12.8±1	20	Audio		(119)
ca. 9.4§	20	4	8	(189)
14.6	20	4	8	(49)
ca. 11	65	4	8	(49)
<b><math>C_{11}H_{12}O_3</math>, Ethyl formylphenylacetate</b>				
3.0	20	4	8	(49)
<b><math>C_{11}H_{12}O_3</math>, Ethyl hydroxymethylenephylacetate</b>				
5.6±1¶	20	4	8	(49)

\*  $k' = 0.12$ .†  $k' = 0.14$ .‡  $k' = 0.08$ .

§ Absorption.

||  $k' = 0.24$ .¶  $k' = 0.27$ .



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>11</sub>H<sub>14</sub>O<sub>2</sub>, Isobutyl benzoate</b>				
5.9	20	3.8	1	(180)
5.51±5*	20	Audio		(119)
5.52±0.1	20	4	8	(49)
4.97±0.1	20	5	8	(41)
$k' = 0.028$	20	2	8	(35)
<b>C<sub>11</sub>H<sub>14</sub>O<sub>3</sub>, Ethyl <i>o</i>-ethoxybenzoate</b>				
7.1±2†	21	4	8	(49)
<b>C<sub>11</sub>H<sub>16</sub>O<sub>2</sub>, 3-Hydroxymethylenecamphor</b>				
12.6(?) §	97	4	8	(49)
5.2(?)§§	30	4	8	(49)
<b>C<sub>11</sub>H<sub>18</sub>O<sub>6</sub>, Triethyl 1, 1, 2-ethanetricarboxylate</b>				
6.58±0.13	19	4	8	(49)
<b>C<sub>12</sub>H<sub>10</sub>, Acenaphthene</b>				
3.0±2	21	4	8	(174)
<b>C<sub>12</sub>H<sub>10</sub>O, Diphenyl ether (supercooled)</b>				
3.9 <i>l</i>	<28	5	8	(41)
<b>C<sub>12</sub>H<sub>11</sub>N, Diphenylamine</b>				
3.35	52 M. P.	Audio		(28)
<b>C<sub>12</sub>H<sub>12</sub>O, <math>\alpha</math>-Naphthyl ethyl ether</b>				
3.25	19.4	5	8	(41)
<b>C<sub>12</sub>H<sub>12</sub>O<sub>4</sub>, Ethyl acetophenoneoxalate</b>				
8.0(?) ¶	46	4	8	(49)
3.3(?)§**	18	4	8	(49)
<b>C<sub>12</sub>H<sub>16</sub>O<sub>2</sub>, Amyl benzoate</b>				
5.15±5††	20	Audio		(119, 180)
4.90±0.1††	20	4	8	(49, 124)
$k' = 0.023$	20	2	8	(35)
<b>C<sub>12</sub>H<sub>16</sub>O<sub>3</sub>, Isoamyl salicylate</b>				
5.4±1	20	5	8	(41)
<b>C<sub>12</sub>H<sub>16</sub>O<sub>6</sub>, Diethyl succinosuccinate</b>				
3(?) <i>l</i>	130	4	8	(49)
2.5(?)§	19	4	8	(49)
<b>C<sub>12</sub>H<sub>18</sub>O<sub>6</sub>, Triethyl aconitate</b>				
6.46±6§§	20	Audio		(119)
5.50±5	70	Audio		(119)
5.75±0.11	20	4	8	(49)
<b>C<sub>12</sub>H<sub>18</sub>O<sub>6</sub>, Triethyl isoconitate</b>				
7.2±1 ¶¶	20	4	8	(49)
4.9±1***	20	4	8	(49)
<b>C<sub>13</sub>H<sub>10</sub>O, Benzophenone</b>				
3.18	25.5	Audio		(191)
13.3 <i>l</i>	20	Audio		(191)
12.4†††	40	Audio		(191)
11.4†††	60	Audio		(191)
<b>C<sub>13</sub>H<sub>12</sub>, Diphenylmethane</b>				
2.6 <i>l</i>	27	4	8	(49)
2.78	17	4	8	(49, 124)
<b>C<sub>13</sub>H<sub>14</sub>O<sub>4</sub>, Ethyl benzoylacetoacetate</b>				
11.8±1	21	Audio		(119)
8.6±2†††	21	4	8	(49)

\*  $\delta_{20} = -1.2$  (119).†  $k' = 0.06$ .‡  $k' = 0.05$ .§  $k' = 0.08$ .¶ Double enol form,  $k' = 0.24$ .\*\*  $k' < 0.02$ .††  $\delta_{20} = -0.7$  (119, 180).‡‡  $k' = 0.02$ .§§  $\delta_{20} = -1.6$ .||  $k' = 0.19$ .¶¶ Enol form,  $k' = 0.11$ .\*\*\* Keto form,  $k' < 0.2$ .

††† Either stable or metastable forms.

‡‡‡  $\gamma$  enol form;  $k' = 0.26$ .

TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b>C<sub>14</sub>H<sub>10</sub>, Phenanthrene; M. P. = 99°</b>				
2.80	20	4	8	(81, 174)
2.79	15			(81)
2.84	40			(81)
2.96	80			(81)
3.13	100			(81)
3.22	110			(81)
3.10	150			(81)
2.96	190			(81)
$\delta_{20} = +0.2$				
<b>C<sub>14</sub>H<sub>10</sub>O<sub>2</sub>, Benzil</b>				
4.20±4	95	Audio		(28)
<b>C<sub>14</sub>H<sub>12</sub>O<sub>2</sub>, Benzyl benzoate</b>				
4.85±0.1	20	5	8	(41)
<b>C<sub>14</sub>H<sub>12</sub>O<sub>3</sub>, Benzyl salicylate</b>				
4.1	20	5	8	(41)
<b>C<sub>14</sub>H<sub>14</sub>N<sub>2</sub>O<sub>3</sub>, <i>p</i>-Azoxyanisole</b>				
4.2	130	Audio		(3)
2.38	50			(3)
2.38	80			(3)
2.58	85			(3)
3.88	90			(3)
4.31*	100			(3)
4.21*	120			(3)
4.11†	135			(3)
4.01†	150			(3)
6.9	130	4	5	(94)
<b>C<sub>14</sub>H<sub>14</sub>N, Dibenzylamine</b>				
3.62±7	20	3.6	8	(124, 164)
<b>C<sub>14</sub>H<sub>16</sub>O<sub>4</sub>, Diethyl benzalmalonate</b>				
7.96±8	0	Audio		(119)
7.63	20	Audio		(119)
6.82	50	Audio		(119)
5.88	70	Audio		(119)
4.4(?)†	20	4	8	(49)
<b>C<sub>14</sub>H<sub>22</sub>O<sub>8</sub>, Tetraethyl propylene-1, 1, 3, 3-tetracarboxylate</b>				
6.9±2§	19	4	8	(49)
<b>C<sub>14</sub>H<sub>24</sub>O<sub>8</sub>, Tetraethyl propane-1, 1, 3, 3-tetracarboxylate</b>				
6.3±2	19	4	8	(49)
<b>C<sub>14</sub>H<sub>24</sub>O<sub>8</sub>, Tetraethyl propane-1, 2, 2, 3-tetracarboxylate</b>				
5.2±1 ¶	19	4	8	(49)
<b>C<sub>14</sub>H<sub>16</sub>N<sub>2</sub>O<sub>3</sub>, <i>p</i>-Azoxyphenetole</b>				
6.8	150	4	5	(94)
<b>C<sub>15</sub>H<sub>33</sub>I, Cetyl iodide</b>				
3.37±6	20	5	8	(41)
<b>C<sub>17</sub>H<sub>21</sub>NO<sub>4</sub>, <i>d</i>-Cocaine</b>				
3.10±4	20	5	8	(176)
<b>C<sub>17</sub>H<sub>21</sub>NO<sub>4</sub>, <i>L</i>-Cocaine</b>				
3.16±4	20	5	8	(176)
<b>C<sub>17</sub>H<sub>30</sub>O<sub>8</sub>, Tetraethyl <math>\alpha</math>-amylene-1, 1, 3, 3-tetracarboxylate</b>				
4.4±1**	19	4	8	(49)
<b>C<sub>17</sub>H<sub>28</sub>O<sub>8</sub>, Tetraethyl pentane-1, 1, 3, 3-tetracarboxylate</b>				
4.8±1††	19	4	8	(49)
<b>C<sub>17</sub>H<sub>28</sub>O<sub>8</sub>, Tetraethyl pentane-2, 2, 4, 4-tetracarboxylate</b>				
4.2±1††	21	4	8	(49)
<b>C<sub>18</sub>H<sub>34</sub>O<sub>2</sub>, Oleic acid</b>				
2.45±0.1	20	4	8	(41, 98)

\* Turbid.

† Homogeneous.

‡  $k' = 0.18$ .§  $k' = 0.16$ .||  $k' = 0.16$ .¶  $k' = 0.17$ .\*\*  $k' = 0.03$ .††  $k' = 0.10$ .‡‡  $k' = 0.08$ .



TABLE 4.—(Continued)

$\epsilon$	$t$	$A$	$n$	Lit.
<b><math>C_{18}H_{33}O_2Na</math>, Sodium oleate</b>				
$2.75 \pm 8s$	20	4	8	(98)
$2.83 \pm 8l$	M. P.	4	8	(98)
<b><math>(C_{18}H_{33}O_2)_2Cu</math>, Copper oleate</b>				
$2.80 \pm 8s$	20	4	8	(98)
$2.80 \pm 8l$	M. P.	4	8	(98)
<b><math>(C_{18}H_{33}O_2)_2Fe</math>, Ferric oleate</b>				
$2.68 \pm 8$	20	4	8	(98)
<b><math>(C_{18}H_{33}O_2)_3Al</math>, Aluminium oleate</b>				
$2.40 \pm 8$	20	4	8	(98)
<b><math>(C_{18}H_{33}O_2)_2Pb</math>, Lead oleate</b>				
$3.27 \pm 0.1s$	18	4	8	(98)
$3.70 \pm 0.1l$	M. P.	4	8	(98)
<b><math>C_{20}H_{34}O_2</math>, Camphorpinacone</b>				
3.65		4	8	(9)
<b><math>C_{22}H_{42}O_2</math>, Isobutyl ricinoleate</b>				
4.7	21	Audio		(191)
<b><math>C_{24}H_{44}O_8</math>, Tetraethyl hexane-1-phenyl-2, 2, 4, 4-tetracarboxylate</b>				
$5.9(?)^*$	20	4	8	(49)
<b><math>C_{28}H_{46}O_8</math>, Tetraethyl pentane-1, 5-diphenyl-2, 2, 4, 4-tetracarboxylate</b>				
$2.7^*$	20	4	8	(49)

\* $k' < 0.02$ .TABLE 5.—DIELECTRIC CONSTANT OF GLYCEROL ( $C_3H_8O_3$ )  
See also Table 6

Melts at  $17^\circ C$ . (a) = state of purity is unknown (68); (b), (c), and (e) = 98% pure (75); (d) = carefully purified (92); (f) = pure (20). Frequency =  $A \times 10^8$  cycle/sec;  $t$  = centigrade temperature,  $^\circ C$ ; for other symbols, see p. 82.

$A$	1.2	3	4.5	6	7.5	2.2
$n$	2	5	5	5	5	8
Purity	(a)	(b)	(c)	(d)	(e)	(f)
$t$	Values of $\epsilon$					
-185	3.21					
-140	3.3					2.8
-100	4.2					2.8
-80	20					2.8
-70	46					2.8
-60	56.5					2.8
-30		36.5	32.5		22	3.0
-26		44.5	39		35	3.0
-20		50.7	48		45	3.0
-15		50.7	50		48.4	3.1
-10		49.8	49.8		49.0	3.2
0		47.2	47.2		47.2	3.7
+20		43.0	43.0	45.8*	43.0*	14.0
40		39.2	39.2	41.2	39.2	33.0
60		35.8	35.8	37.5	35.8	35.0
80		32.8	32.8	34.8	32.8	32.8
100		30.2	30.2	32.5	30.2	30.2
120				30.7		29.0
140				29.0		28.0
200						25.8

$A$	$n$	$t$	$\epsilon$	$k'$	Lit.
7.5	5	20	43.0		(75)
1.3	8	15	$36.2 \pm 1.2$	0.27	(44, 46)
4	8	15	$19.0 \pm 6$	0.50	(44, 46)
4	8	20	$16.5 \pm 6$	0.42	(48, 49)
7	9	15	$15 \pm 2$		(125)

\* $\partial n = -21 \pm 8$ .

TABLE 6.—DISPERSION AND ABSORPTION DATA: ORGANIC COMPOUNDS AND SOLUTIONS

For no organic compound, other than those in this table, are data available for the variation of  $n$  and of  $nk'$  over a wide range of frequency ( $\nu$ ), but data for one or two values of  $\nu$  are available for a number of other substances. The values of  $k'$  for these substances are given in Table 4.

$n$  = index of refraction,  $k'$  = index of absorption,  $\lambda_0$  = wavelength in a vacuum. If  $E_x$  = energy at  $x$  of a train of plane waves travelling in the direction of axis of  $x$ , then  $E_x = E_0 e^{-4\pi nk'x/\lambda_0}$ ,  $\nu = A \times 10^8$ . Unit of  $\nu$  = 1 cycle/sec; of  $\lambda_0$  = 1 cm;  $t$  = centigrade temperature,  $^\circ C$ .

**CH<sub>4</sub>O, Methyl alcohol**

$n$	$nk'$	$t$	$A$	$s$	$\lambda_0$	Lit.
5.65	0.32	18	3.35	8	90	(143, 151)
5.70 $\pm 5$		18	4	8	75	(44, 143)
	0.37 $\pm 1$	18	4	8	75	(11, 48, 143, 151, 196)
	0.48	9	4	8		(11)
	0.33	21	4	8		(11)
	0.36	18	5	8	60	(151)
5.65	0.48	18	5	8	60	(143)
	0.40	18	6	8	50	(151)
5.65	0.66	18	6	8	50	(143)
5.70	1.32	18	7.5	8	40	(143)
6.05	2.33	18	9	8	33	(143)
3.8	1.45	17	5	9	5.7	(53)
5.4			6.7	9	4.5	(125)
3.6	1.38	18	8	9	3.7	(53)
2.8	0.80	17	1.7	10	1.75	(53)

**C<sub>2</sub>H<sub>6</sub>O, Ethyl alcohol (99.5%); see Fig. 2**

5.17			3.3	7	900	(198)
5.20		18	{ 5	7	600	(32)
			{ 1	8	300	(32)
5.24		18	1.16	8	259	(32)
4.92 $\pm 5$		18	1.4	8	220	(44)
	0.79	18.7	3	8	100	(151)
4.51 $\pm 6$	0.75 $\pm 5$	19	3.5	8	85	(33, 143, 151)
	0.95 $\pm 2$	18	4	8	75	(11, 46, 48, 143, 151)
	1.08	13	4	8	75	(11)
	0.86	21	4	8	75	(11)
4.00		17	4	8	75	(33)
4.37		16	4	8	75	(143)
4.80		16	4	8	75	(44, 48)
4.3 $\pm 1$	1.00	19	4.75	8	63	(33, 143, 151, 196)
4.38		17	5.7	8	53	(122)
	0.90	19	6	8	50	(151)
3.7	1.1	19	6	8	50	(143)
3.5	1.9	19	8	8	37.5	(143)
3.9	3.2	19	1	9	30	(143)
	1.48	19	1.36	9	22.2	(196)
3.6	0.60	17	5.3	9	5.7	(53)
3.2		18	6	9	5	(32)
2.25			6.7	9	4.5	(126)
2.97		17	7.5	9	4	(122)
3.4	0.45	15	8.1	9	3.7	(53)
2.8	0.43	17	9	9	3.3	(130)
3.4	0.39	17	1.72	10	1.75	(53)
2.4	0.30	ca. 19	2	10	1.5	(130)
2.1	0.20	ca. 19	3.3	10	0.9	(130)
2.57			3.8	10	0.8	(109)
2.29			5	10	0.6	(109)
2.24			7.5	10	0.4	(109)



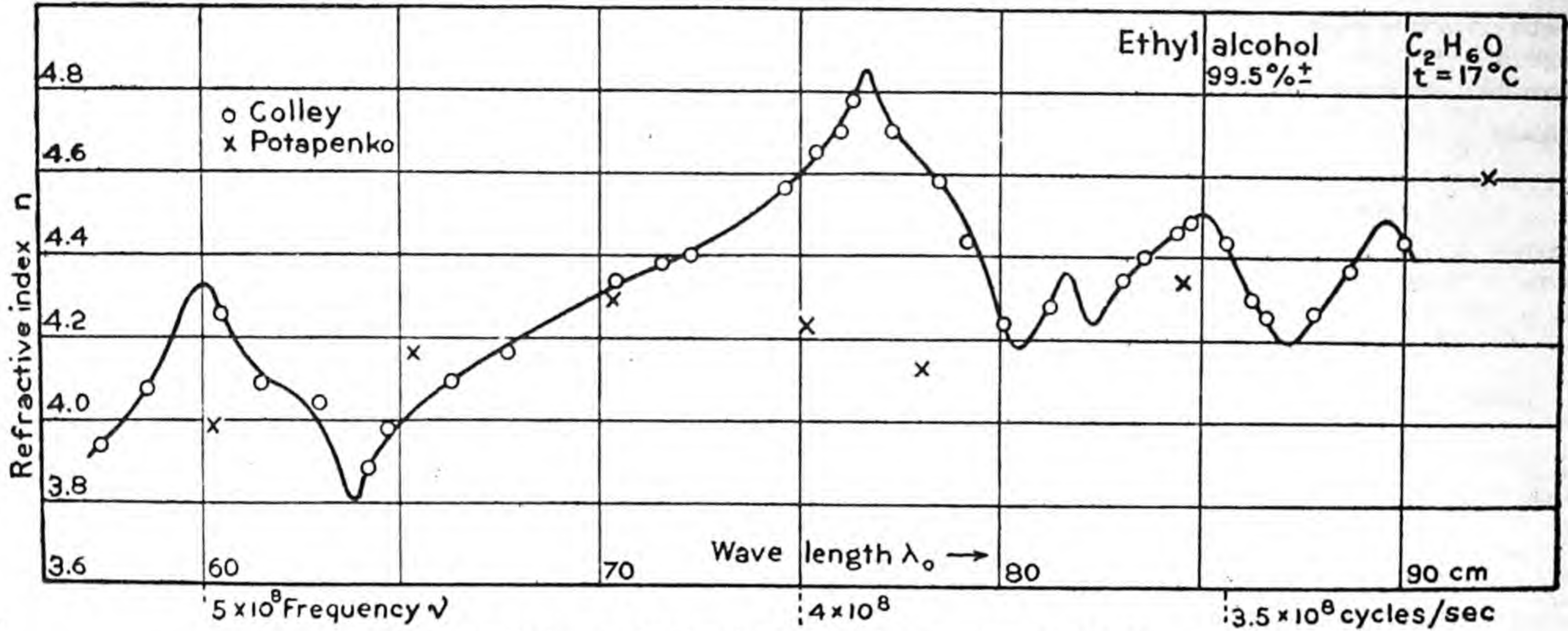


FIG. 2.—Variation of refractive index with wave-length (33, 143).

TABLE 6.—(Continued)  
 $C_2H_6O + xH_2O$ , Ethyl alcohol and water

% Alc.	$nk'$	$t$	$A$	$s$	$\lambda_0$	Lit.
96	0.98	14.5	4.05	8	74	(11)
96	0.82	21	4.05	8	74	(11)
90	0.69		3.5	8	86	(151)
90	0.77		4	8	75	(151)
90	0.79		4.75	8	63	(151)
90	0.92		4.75	8	63	(196)
75	0.75		4.75	8	63	(196)
55 <sup>a</sup>	0.53		4.75	8	63	(196)

$C_2H_6O$ , Acetone (34)

$C_3H_8O$ , n-Propyl alcohol

$n$	$nk'$	$t$	$A$	$s$	$\lambda_0$	Lit.
3.84	1.57	15	4.1	8	73	(48, 49)
	1.20	20	4.05	8	74	(11)
	1.36	11	4.05	8	74	(11)
	1.5		4.76	8	63	(196)
	0.95		1.36	9	22.2	(196)
2.8	0.58	17	5.3	9	5.7	(53)
2.8	0.50	16	8.1	9	3.7	(53)
2.8	0.30	17	1.72	10	1.75	(53)

$C_3H_8O_3$ , Glycerol

6.2±2	1.7		1.4	8	220	(44, 46)
	1.20	12	4.05	8	74	(11)
	1.47	20	4.05	8	74	(11)
	1.59	27	4.05	8	74	(11)
5.0	2.5	15	4.1	8	73	(46, 48)
4.5	1.9	20	4.1	8	73	(48, 49)
3.74			3.52	9	8.52	(111)
3.8	0.23	17	5.3	9	5.7	(53)
4.1			6.7	9	4.5	(125)
3.8	0.26	15	8.1	9	3.7	(53)
3.8	0.27	19	1.72	10	1.75	(53)
1.84			3.7	10	0.8	(109)
1.76			5	10	0.6	(109)
1.62			7.5	10	0.4	(109)

$\nu = 2.2 \times 10^8$ ,  $\lambda_0 = 136$  (20)

$n$	$nk'$	$t$	$n$	$nk'$	$t$
1.67	0.02	-140	1.73	0.02	-20
1.67	0.02	-100	1.93	0.14	0
1.70	0.02	-40	2.36	0.52	+10

$C_3H_8O_3$ —(Continued)

$n$	$nk'$	$t$	$n$	$nk'$	$t$
3.96	1.31	20	5.67	0.11	80
5.20	1.40	30	5.50	0.11	100
5.82	0.93	40	5.38	0.11	120
5.99	0.42	50	5.08	0.10	200
5.91	0.30	60			

$C_4H_{10}O$ , Isobutyl alcohol

$n$	$nk'$	$t$	$A$	$s$	$\lambda_0$	Lit.
	1.19	19	3	8	100	(151)
	1.14	19	4	8	75	(31, 151)
2.80	1.32	18	4.1	8	73	(48, 49)
	1.4		4.76	8	63	(196)
	1.10	19	5	8	60	(151)
	1.10	19	5.5	8	55	(151)
	1.01	19	6	8	50	(151)
	0.91	19	6.7	8	45	(151)
	0.42		1.36	9	22.2	(196)
2.4	0.31	17	5.3	9	5.7	(53)
2.4	0.26	17	8.1	9	3.7	(53)
2.4	0.25	18	1.72	10	1.75	(53)

$C_5H_{12}O$ , Amyl alcohol

3.03±5		17.3	1.4	8	220	(44)
	0.97	19	3	8	100	(151)
	0.88	19	4	8	75	(151)
2.34±5	1.20	18.5	4.1	8	73	(44, 46)
	1.01	22	4.1	8	73	(48, 49)
	0.80	19	5	8	60	(151)
	0.69	19	6	8	50	(151)
1.82			6.7	9	4.5	(125)

$C_6H_6$ , Benzene; see Fig. 1

$C_7H_8$ , Toluene; see Fig. 1

TABLE 7.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF CRYSTALS

$\epsilon_{||}$ ,  $\epsilon_{\perp}$  = value of  $\epsilon$  when direction of the electric field is  $\parallel$ ,  $\perp$  to optic axis; crystal being uniaxial.  $\epsilon_a$ ,  $\epsilon_b$ ,  $\epsilon_c$  = value of  $\epsilon$  when direction of electric field is  $\parallel$  to brachy (a), macro (b), c crystallographic axis, respectively; crystal orthorhombic.  $\epsilon_1$ ,  $\epsilon_2$  = value of  $\epsilon$  along principal axes of the electric indicatrix  $\perp$  to ortho (b) axis in monoclinic crystals;  $\epsilon_1 > \epsilon_2$ .  $\chi$  = angle between the crystallographic c-axis and the direction corresponding to  $\epsilon_1$ .



positive in direction from  $c$ -axis towards  $a$ -axis. The acute crystal angle  $\beta = +c_{1-2}$  is, therefore, negative. The value of  $\epsilon$  in any given direction is numerically equal to that semidiameter of the ellipsoid  $\frac{x^2}{\epsilon_1^2} + \frac{y^2}{\epsilon_2^2} + \frac{z^2}{\epsilon_3^2} = 1$  which is  $\parallel$  to the given direction.

$\epsilon_{\perp}$  = value when field is  $\perp$  plane of cleavage,  $\epsilon_m$  = mean value of  $\epsilon$ ; for uniaxial crystals,  $\epsilon_{\parallel} + 2\epsilon_{\perp} = 3\epsilon_m$ ; for orthorhombic crystals,  $\epsilon_a + \epsilon_b + \epsilon_c = 3\epsilon_m$ ; for monoclinic,  $\epsilon_1 + \epsilon_2 + \epsilon_3 = 3\epsilon_m$ ; trans. = transparent; trl. = translucent. For other symbols, see p. 82. Unit of  $\epsilon = 1$  cgse unit; of  $\chi = 1^\circ$ . Frequency,  $\nu = A \times 10^6$  cycle/sec.

## Isometric (or regular, or cubic) system, optically isotropic

		$\epsilon$	$A$	$n$	Lit.
NH <sub>4</sub> Cl	Ammonium chloride.....	6.8	1	12	(114)
NH <sub>4</sub> Br	Ammonium bromide.....	7.3	1	12	(114)
P	Phosphorus (yellow).....	3.60	3	18	(167)
C	Diamond.....	5.5	3	18	(167)
AgCl	Silver chloride.....	11.20	1	5; 7	(90)
AgBr	Silver bromide.....	12.17	1	5; 7	(90)
Pb(NO <sub>3</sub> ) <sub>2</sub>	Lead nitrate.....	16.8	1	12	(114)
Al <sub>2</sub> (NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>4</sub> ·24H <sub>2</sub> O	Ammonium alum.....	6.0	1	12	(114)
CaF <sub>2</sub>	Fluorite (colorless).....	6.85*	Audio		(30, 162, 175)
		6.75 ± 4	1	5; 12	(90, 114, 150, 156)
NaCl	Rock salt.....	6.2 ± 0.1	Audio		(30, 140, 181)
		5.75 ± 8	1	5; 9	(90, 155, 156, 166, 181)
		5.9 ± 0.1	1	12	(114, 155, 156)
NaAlSi <sub>3</sub> O <sub>8</sub> ·H <sub>2</sub> O	Analcite.....	6.7	1	12	(114)
KBr	Potassium bromide.....	5.1	1	12	(114)
KI	Potassium iodide.....	5.4	1	12	(114)
K <sub>2</sub> Al <sub>2</sub> (SO <sub>4</sub> ) <sub>4</sub> ·24H <sub>2</sub> O	Potassium alum.....	6.5 ± 0.2*	Audio		(26, 175)
	(19°C).....	6.32	3	8	(166)
Rb <sub>2</sub> Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>4</sub> ·24H <sub>2</sub> O	Rubidium chrome alum.....	5.0	1	12	(114)
Rb <sub>2</sub> Al <sub>2</sub> (SO <sub>4</sub> ) <sub>4</sub> ·24H <sub>2</sub> O	Rubidium alum.....	5.1	1	12	(114)
Cs <sub>2</sub> Al <sub>2</sub> (SO <sub>4</sub> ) <sub>4</sub> ·24H <sub>2</sub> O	Cesium alum.....	5.0	1	12	(114)

## Tetragonal, trigonal, and hexagonal systems, optically uniaxial

		$\epsilon_{\perp}$	$\epsilon_{\parallel}$	$A$	$n$	Lit.
SiO <sub>2</sub>	Chalcedony.....	$\epsilon_m = 4.2$		1	12	(114)
TiO <sub>2</sub>	Rutile (brown) (19°C).....	80 ± 3	170 ± 3	1	8; 12	(115, 166)

## Tetragonal, trigonal, and hexagonal systems.—(Continued)

		$\epsilon_{\perp}$	$\epsilon_{\parallel}$	$A$	$n$	Lit.
TiO <sub>2</sub>	Rutile (trans.).....	$\epsilon_m = 78 \pm 5$		3	8	(166)
		$\epsilon_m = 31$		3	8	(166)
ZrSiO <sub>4</sub>	Zircon (trans., yellow).....	12 ± 1	12 ± 1	1	8; 12	(115, 166)
SnO <sub>2</sub>	Cassiterite.....	23.4	24.0	1	12	(114)
Pb <sub>3</sub> Cl(PO <sub>4</sub> ) <sub>2</sub>	Pyromorphite (trl., yellow).....	26	150 ± 15	3	8	(166)
(Zn, Fe, Cd)S	Wurtzite.....	$\epsilon_m = 8.2$		1	12	(115)
ZnCO <sub>3</sub>	Smithsonite.....	9.3	9.4	1	12	(114)
HgCl	Calomel.....	14.0†		1	12	(114)
FeCO <sub>3</sub>	Siderite.....	8.5 ± 0.3*	8.0 ± 0.3	2	0	(26)
	(trl.).....	7.85	6.85	3	8	(166)
		7.8	6.0	1	12	(114)
PbMoO <sub>4</sub> (?)	Wulfenite (red).....		26.8	3	8	(167)
		$\epsilon_m = 23.8$		3	8	(167)
Al <sub>2</sub> O <sub>3</sub>	Corundum; sapphire.....	13.19	11.42	Audio		(66)
	(synthetic).....	12.80	11.08	Audio		(66)
Al <sub>2</sub> O <sub>3</sub>	Ruby.....	13.27	11.28	Audio		(66)
	(synthetic).....	13.38	11.08	Audio		(66)
H <sub>2</sub> Al <sub>2</sub> (BOH) <sub>2</sub> -Si <sub>2</sub> O <sub>7</sub> (?)	Tourmaline (clear).....	7.10†	6.3 ± 2	Audio		(26, 66)
	(bright green, trans.).....	6.77	5.59	3	8	(166)
		7.1	6.1	1	12	(114)
Be <sub>3</sub> Al <sub>2</sub> (SiO <sub>3</sub> ) <sub>2</sub>	Beryl (trans., blue) (19°C).....	6.08	5.58	3	8	(166)
	(trans., green) (19°C).....	6.05	5.50	3	8	(166)
	(emerald).....	7.6†	6.2	1	0	(30)
	(aquamarine).....	7.02	6.08	Audio		(66)
	(aquamarine).....	7.4	7.8	Audio		(175)
		5.95 ± 5	5.9 ± 0.1	1	12	(114)
H <sub>2</sub> (Mg, Fe)Al <sub>2</sub> -Si <sub>2</sub> O <sub>7</sub>	Penninite (trans., green) (19°C).....	$\epsilon_m = 4.85$		3	8	(166)
Ca <sub>2</sub> (Cl, F)(PO <sub>4</sub> ) <sub>2</sub>	Apatite (lilac) (19°C).....	9.50†	7.41	3	8	(166)
		10.5	7.7	1	12	(114)
CaCO <sub>3</sub>	Calcite.....	8.5 ± 0.2	8.0 ± 0.3	Audio		(65, 141, 152, 175)
	(Iceland) (19°C).....	8.5 ± 0.2	8.0 ± 0.2	3	8	(166)
	(deduced) (27.8°C).....	$\epsilon_{\perp} = 7.8$		Audio		(146)
	(deduced) (27.8°C).....	$\epsilon_{\parallel} = 8.3 \pm 0.1$		1	8; 12	(155, 166, 181)
CaCO <sub>3</sub>	Marble.....	$\epsilon_m = 8.30$		2	2; 8	(66, 90, 155, 167)
		$\epsilon_m = 8.5 \pm 0.3$		1	9; 12	(114, 156, 156)
Ca <sub>2</sub> Al(OH, F)-Al <sub>2</sub> (SiO <sub>3</sub> ) <sub>2</sub> (?)	Vesuvianite (trans.).....	8.5 ± 0.1	9.2 ± 0.2	1	8; 12	(114, 166)
CaMg(CO <sub>3</sub> ) <sub>2</sub>	Dolomite.....	8.0 ± 0.2	6.8 ± 0.1	1	8; 12	(114, 166)
NaNO <sub>2</sub>	Soda nitre.....	6.5		1	12	(114)
KLiSO <sub>4</sub>	Potassium lithium sulfate.....	5.4	5.7	1	12	(114)
NaK <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub>	Sodium tripotassium sulfate.....	7.2	5.8	1	12	(114)

For footnotes, see p. 100.

## Monoclinic system, optically biaxial

		$\epsilon_1$	$\epsilon_m$	$\epsilon_2$	$\epsilon_{\perp}$	$\epsilon_{\parallel}$	$\chi$	$A$	$n$	Lit.
C <sub>12</sub> H <sub>22</sub> O <sub>11</sub>	Cane sugar.....	3.49		3.32		3.16	-58.7	3	8	(52)
Zn(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		6.6		7.6		5.4	-82.1	1.7	2	(22)
CuCO <sub>3</sub> ·Cu(OH) <sub>2</sub>	Malachite.....		7.2					1	12	(114)
Mn(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		5.9		6.8		4.6	26.0	1.7	2	(22)
Co(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		6.1		5.6		5.8	41.9	1.7	2	(22)
Ni(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		5.4		5.1		5.1	11.1	1.7	2	(22)
Mg(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		7.1		8.5		6.1	-28.9	1.7	2	(22)
CaSO <sub>4</sub> ·2H <sub>2</sub> O	Gypsum.....				6.3			2	0	(36)
					5.04			Audio		(175)
					5.10			1	5; 7	(90, 181)
					7.5			1	12	(155)
		9.92		5.15		5.04	102.5	3	8	(166)
CaMg <sub>2</sub> Si <sub>2</sub> O <sub>7</sub> ·x(Mg, Fe)(Al, Fe)SiO <sub>3</sub> (?)	Augite.....	11.6				5.4	-1.0	1	12	(157)
		8.57		6.90		7.07	-55.6	3	8	(52)
		10.3				7.3	-55	1	12	(157)
			6.2	5.9				1.7	2	(22)
Na <sub>2</sub> HAsO <sub>4</sub> ·12H <sub>2</sub> O		9.4		10.7		8.5	-75.1	1.7	2	(22)
K <sub>2</sub> Co(SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		6.4		7.1		5.5	15.0	1.7	2	(22)
K <sub>2</sub> Ni(SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		5.38		5.50		4.54	42.5	3	8	(52)
KAlSi <sub>3</sub> O <sub>8</sub>	Adular.....	6.2				4.8	2.5	1	12	(157)



## Orthorhombic system, optically biaxial

		$\epsilon_a$	$\epsilon_m$	$\epsilon_b$	$\epsilon_{ct}$	$\epsilon_c$	A	n	Lit.
S	Sulfur.....		4.0				2	0	(36)
		3.81		3.97		4.77	3.2	1	(21)
		3.67		3.87		4.66	1.7	2	(22)
	(trans., from CS <sub>2</sub> ) (19°C).....	3.59		3.88		4.61	3	8	(166)
C <sub>6</sub> H <sub>8</sub> O <sub>7</sub>	Citric acid.....	4.7		4.3		3.3	1.7	2	(22)
PbCl <sub>2</sub>	Lead chloride.....		42 ± 2.0				3	8	(167)
			40 ± 3.0				1	12	(114, 155)
PbCO <sub>3</sub>	Cerussite.....	25.4		23.0		19.6	3	8	(166)
		24.2 ± 0.3		25.0 ± 0.3		26.3 ± 0.3	1	12	(114)
HgCl <sub>2</sub>	Mercuric chloride.....		6.55 ± 5				1	12	(114, 155)
(AlF) <sub>2</sub> SiO <sub>4</sub>	Topaz.....				6.53*		2	0	(36)
		6.25		6.53		6.44	Audio		(66)
	(trans., yellow) (19°C).....	6.68		6.71		6.28	3	8	(166)
		7.4		7.3		7.6	1	12	(114)
MgSO <sub>4</sub> ·7H <sub>2</sub> O	Magnesium sulfate.....	5.3		6.1		8.3	1.7	2	(22)
CaSO <sub>4</sub>	Anhydrite (trans.) (19°C).....			5.70 ± 5		6.30 ± 5	1	8; 12	(114, 166)
CaCO <sub>3</sub>	Aragonite.....	9.1				6.0	Audio		(65)
	(19°C).....	9.87 ± 3		7.72 ± 3		6.59 ± 3	3	8	(166)
		6.7		10.5		7.6	1	12	(114)
SrSO <sub>4</sub>	Celestite (trans.).....	7.9§		18.5		8.30	3	8	(166)
		9.3		44†		8.5	1	12	(114)
SrCO <sub>3</sub>	Strontianite.....	6.6				6.5	1	12	(115)
BaSO <sub>4</sub>	Barite.....	7.0		11.0		7.0	Audio		(65)
		7.68		12.2		7.70	3	8	(166)
		9.1				9.8	1	12	(114)
BaCO <sub>3</sub>	Witherite (19°C).....	7.8 ± 0.1		7.5 ± 0.1		6.4 ± 0.1	3	8	(166)
				7.5		7.3	1	12	(114)
KNaC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> ·4H <sub>2</sub> O	Rochelle salt¶ (0°C).....	800					0	0	(186)
	(0°C).....	700					3.3	1	(186)
		6.7		6.9		8.9	1.7	2	(22)
	0°C.....	112					40; 8	3	(70)
	0°C.....	70					4	5; 7	(70)
	15°C.....	80					4	5; 7	(70)
K <sub>2</sub> SO <sub>4</sub>	Potassium sulfate.....	6.1		5.7		4.5	1.7	2	(22)

## Triclinic system (no data available)

\* Very small absorption.

† Probably too great.

‡ Large absorption.

§ Local impurities, inclusions.

|| Colorless.

¶ Behavior anomalous -20 to +25°C. At low frequencies, measurements are affected by mechanical vibration, fatigue, and absorption.

TABLE 8.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF BINARY MIXTURES AND SOLUTIONS

For data below -80°C, see Table 10; for solutions of oleates, see Table 9; for mixtures of gases, see Table 3; for colloidal suspensions, see Table 11.

Concentrations are expressed in terms of the amount of the B-component contained in the mixture, except in a few cases in which the A-component is a solid, or the volume % of A is given. An asterisk (\*) indicates that all values of that series have been recalculated so as to make them correspond to the values adopted (Table 1) for the standardizing liquids.

The frequency (cycles per sec) of the applied emf and the temperature are given immediately below the B-component.

The concentration of component (A), (B) is indicated in each case by one of the symbols M<sub>B</sub>, M %, N', Vol. %, Wt. %. M<sub>B</sub> = molar concentration, unit = 1 gram mole B per liter of solution; M % B = molecular percentage, unit = 1 gram mole B per 100 gram moles of the mixture, the total number of moles of the mixture being assumed equal to the sum of those of its pure constituents; N' = thousandth normal, unit = 1 gram equivalent of B per 1000 liters of the mixture; Vol. % = volume percentage, unit = 1 cm<sup>3</sup> of pure A, or B, per 100 cm<sup>3</sup> of mixture; Wt. % B = weight

percentage, unit = 1 gram B per 100 grams of mixture. t = centigrade temperature, °C; for other symbols, see p. 82.

## 1. Aqueous Solutions

Unit of  $\epsilon$  = 1 cgse unit

B = CH <sub>4</sub> N <sub>2</sub> O, Urea (80)	B = CH <sub>3</sub> O.— (Continued)	B = C <sub>2</sub> H <sub>5</sub> Cl <sub>2</sub> O, Chloral hydrate (174)
M <sub>B</sub>   $\epsilon$	Wt. % B   $\epsilon$	M % B   $\epsilon$
5.6 × 10 <sup>5</sup> ; 20°C (80)		4 × 10 <sup>5</sup> ; 21.8°C
0.5   80.22	20.0   72.8	40.8   33.5 ± 1.0
1.0   81.51	40.0   63.0	
1.5   82.81	60.0   52.2	
2.0   83.98	80.0   42.6	
2.5   85.16	100.0   33.8	
3.0   86.17		
	5.6 × 10 <sup>5</sup> ; 18°C (89)	
B = CH <sub>3</sub> O, Methyl alcohol (49)		B = C <sub>2</sub> H <sub>5</sub> NO, Acetamide (174)
Wt. % B   $\epsilon$		M % B   $\epsilon$
4 × 10 <sup>5</sup> ; 17°C		4 × 10 <sup>5</sup> ; 21.7°C
0.0   82.6*	20.0   69.6	40.7   7.2 ± 0.2
10.0   77.6	40.0   61.4	
	60.0   52.4	
	80.0   43.1	
	100.0   33.8	



<b>B = C<sub>2</sub>H<sub>4</sub>NO<sub>2</sub>, Glycocoll (72)</b>	
Wt. % B   $\epsilon$	
4 × 10 <sup>3</sup> ; 20°C	
0.0	81.9*
1.0	86.9
4.0	90.8
8.0	93.4
16.0	94.7

<b>B = C<sub>2</sub>H<sub>5</sub>O, Ethyl alcohol (133)</b>	
See also Table 6	
Wt. % B   $\epsilon$	
Audio; 20°C	
50.0	49.4*
60.0	43.9
70.0	38.7
80.0	34.1
90.0	29.8
100.0	26.5

<b>B = C<sub>3</sub>H<sub>6</sub>O, Acetone (49)</b>	
4.0 × 10 <sup>3</sup> ; 19°C	
0.0	81.8*
25.0	67.7
50.0	51.2
80.0	32.2
100.0	20.7

<b>B = C<sub>3</sub>H<sub>7</sub>O<sub>2</sub>, Propionic acid (49)</b>	
4 × 10 <sup>3</sup> ; 17°C	
55.0	43.8*
60.0	29.7
62.5	25.4
65.0	24.9
70.0	24.7
75.0	23.4
80.0	19.4
90.0	10.9
95.0	6.8

<b>B = C<sub>3</sub>H<sub>7</sub>NO<sub>2</sub>, Urethane (174)</b>	
M % B   $\epsilon$	
4 × 10 <sup>3</sup> ; 21.7°C	
35.5	32 ± 1

<b>B = C<sub>4</sub>H<sub>5</sub>NO<sub>2</sub>, Succinimide (174)</b>	
M % B   $\epsilon$	
4 × 10 <sup>3</sup> ; 22.3°C	
5.2	5.8 ± 1.0

<b>B = C<sub>6</sub>H<sub>6</sub>O<sub>2</sub>, Resorcinol (174)</b>	
M % B   $\epsilon$	
4 × 10 <sup>3</sup> ; 21.8°C	
17.8	3.2 ± 0.2

<b>B = C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>, Dextrose (72)</b>	
Wt. % B   $\epsilon$	
4 × 10 <sup>3</sup> ; 20°C	
0.0	81.9*
10.0	68.4
20.0	55.7
30.0	42.8
40.0	30.3

<b>B = C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>, Levulose (72)</b>	
4 × 10 <sup>3</sup> ; 20°C	
0.0	81.9*
10.0	73.8
20.0	59.3
30.0	45.4
40.0	31.4

<b>B = C<sub>6</sub>H<sub>14</sub>O<sub>6</sub>, Mannitol (174)</b>	
M % B   $\epsilon$	
4 × 10 <sup>3</sup> ; 22.0°C	
1.8	3.0 ± 0.2

<b>B = C<sub>7</sub>H<sub>5</sub>NO<sub>3</sub>S, Saccharin (72)</b>	
Wt. % B   $\epsilon$	
4 × 10 <sup>3</sup> ; 20°C	
0.0	81.9*
0.10	85.5
0.25	91.1
0.50	87.7
1.00	78.6
2.00	73.6
10.0	58.5
20.0	48.3
30.0	39.2

<b>B = C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>, Cane sugar (72)</b>	
4 × 10 <sup>3</sup> ; 20°C	
0.0	81.9*
10.0	80.9
20.0	75.3
30.0	68.2
50.0	49.9
60.0	39.7
5.6 × 10 <sup>3</sup> ; 18°C (80)	
5.0	77.14
10.0	76.16
20.0	74.05
25.0	72.94
30.0	71.52

<b>B = C<sub>15</sub>H<sub>27</sub>NO<sub>3</sub>S, Tetraethyl ammo- nium naphthalene- β-sulfonate (112)</b>	
N'   $\epsilon$	
7 × 10 <sup>3</sup> ; 20°C	
2	75.1
5	66.9

<b>B = Albumin (72)</b>	
Wt. % B   $\epsilon$	
4 × 10 <sup>3</sup> ; 20°C	
0.0	81.9*
0.50	71.8
1.00	67.0
4.00	52.3
6.00	47.8
15.00	33.4

<b>B = Gelatin (72)</b>	
4 × 10 <sup>3</sup> ; 20°C	
0.0	81.9*
5.00	68.2
10.0	60.2
20.0	53.4
30.0	49.6
50.0	44.8

<b>B = Pepsin (72)</b>	
4 × 10 <sup>3</sup> ; 20°C	
1.0	79.9*
2.0	77.4

<b>B = Trypsin (72)</b>	
4 × 10 <sup>3</sup> ; 20°C	
0.25	83.9*
0.50	85.5

<b>B = CuSO<sub>4</sub>, Copper sulfate (112)</b>	
N'   $\epsilon$	
7 × 10 <sup>3</sup> ; 20°C	
1.14	73.5
2.28	75.8
4.58	72.1

<b>B = KCl, Potassium chloride (112)</b>	
9 × 10 <sup>3</sup> ; 20°C	
0.755	78.6
7 × 10 <sup>3</sup> ; 20°C	
0.755	73.4
1.51	74.4
7.55	65.1

For various other electrolytes consult the current literature.

## 2. Non-Aqueous Solutions; The C-Arrangement; v. Vol. III, p. viii

<b>CCl<sub>4</sub> Carbon tetrachloride</b>	
<b>B = CS<sub>2</sub>, Carbon disulfide (42, 77, 116)</b>	
Wt. % B   $\epsilon$	
Audio; 20°C	

20	2.31
40	2.39
60	2.47
80	2.56
100	2.66
Wt. % B   $\delta$	
(10 t 45)	
20	- 0.14
40	- 0.15
(10 t 55)	
60	- 0.18
(10 t 40)	
80	- 0.18

<b>B = C<sub>2</sub>H<sub>4</sub>Br<sub>2</sub>, Ethylene bromide (42)</b>	
Wt. % B   $\epsilon$	
Audio; 23°C	
30	2.59
50	3.02
70	3.38
90	3.85

<b>B = C<sub>2</sub>H<sub>5</sub>O, Ethyl alcohol (105)</b>	
10 <sup>3</sup> ; 20°C	
0	2.25
10	5.40
20	8.60
30	11.7
40	14.5
50	17.0
60	19.1
70	20.9
80	22.6
90	24.2
100	25.8

<b>B = C<sub>4</sub>H<sub>10</sub>O, Ethyl ether (42)</b>	
Audio; 19.0°C	
0.0	2.26
20.0	2.98
40.0	3.53
80.0	4.25
100.0	4.55

<b>B = C<sub>6</sub>H<sub>5</sub>Cl, Chlorobenzene (16)</b>	
Vol. % A   $\epsilon$	
Audio; 15°C	
20	2.91
30	3.35
50	3.95
80	5.02

<b>B = C<sub>6</sub>H<sub>6</sub>, Benzene (116)</b>	
M % B   $\epsilon$	
Audio; 20°C	
0.0	2.27*
25.0	2.22
60.0	2.22
75.0	2.23
100.0	2.28

<b>B = C<sub>7</sub>H<sub>16</sub>O, Ethyl amyl ether (42)</b>	
Wt. % B   $\epsilon$	
Audio; 22.9°C	
20.0	2.64
50.0	3.17
70.0	3.28
90.0	3.40

<b>B = C<sub>8</sub>H<sub>10</sub>, m-Xylene (42)</b>	
Audio; 20°C	
10	2.27
40	2.31
70	2.34
90	2.37

B = Oleates, see Table 9

<b>CS<sub>2</sub> Carbon disulfide</b>	
<b>B = S, Sulfur (54)</b>	
Wt. % B   $\epsilon$	
4 × 10 <sup>3</sup> ; 19°C	
0.0	2.67*
5.0	2.44
10.0	2.22
20.0	2.10
25.0	2.10

<b>B = CHCl<sub>3</sub>, Chloroform (139)</b>	
Audio; 18°C	
20.0	2.95*
30.0	3.17
40.0	3.38
60.0	3.78
80.0	4.23
Audio; 19°C (42)	
20.0	2.70
40.0	3.28
80.0	4.47

<b>B = C<sub>2</sub>H<sub>4</sub>Br<sub>2</sub>, Ethylene bro- mide (42)</b>	
Audio; 22.4°C	
40.0	3.02
60.0	3.37
70.0	3.68
90.0	4.36

<b>B = C<sub>2</sub>H<sub>5</sub>O, Ethyl alcohol (139)</b>	
Wt. % B   $\epsilon$	
Audio; 18°C	
30.0	22.7*
40.0	19.80
60.0	14.00
80.0	8.25
100.0	2.64

<b>B = C<sub>4</sub>H<sub>10</sub>O, Ethyl ether (116)</b>	
Audio; 20°C	
0.0	2.65*
40.0	3.33
80.0	4.00
100.0	4.39

<b>B = C<sub>6</sub>H<sub>5</sub>Br, Bromobenzene (42)</b>	
Audio; 20°C	
20.0	3.03
40.0	3.72
60.0	4.42
80.0	5.12
100.0	5.82

<b>B = C<sub>6</sub>H<sub>6</sub>, Benzene (77)</b>	
10 <sup>3</sup> ; 20°C	
40.0	2.384
60.0	2.321
80.0	2.305
Wt. % B   $\delta$	
(10 t 40)	
40.0	- 0.16
60.0	- 0.17
80.0	- 0.19

<b>B = C<sub>7</sub>H<sub>8</sub>, Toluene (42)</b>	
Wt. % B   $\epsilon$	
Audio; 20.0°C	
20.0	2.60
50.0	2.52
70.0	2.44
90.0	2.35

<b>B = C<sub>7</sub>H<sub>16</sub>, Heptane (42)</b>	
Audio; 22.5°C	
0.0	2.74
10.0	2.50
30.0	2.21
40.0	2.205
50.0	2.202
60.0	2.15

<b>B = C<sub>8</sub>H<sub>10</sub>, m-Xylene (16)</b>	
Vol. % B   $\epsilon$	
Audio; 15°C	
0.0	2.61
40.0	2.52
60.0	2.47
80.0	2.43
100.0	2.37



CS<sub>2</sub>.—(Cont'd)

B = Oleates; see Table 9

CHCl<sub>3</sub>

Chloroform

B = C<sub>2</sub>H<sub>4</sub>Br<sub>2</sub>,

Ethylene bromide (42)

Wt. % B	ε
Audio; 22.4°C	
20.0	4.89
40.0	4.88
60.0	4.87
70.0	4.86
90.0	4.84

B = C<sub>2</sub>H<sub>5</sub>O, Ethyl alcohol (42, 77)

Audio; 20°C

20.0	4.33
40.0	3.74
60.0	3.15
80.0	2.64

Wt. % B	δ <sub>20</sub>
20.0	-1.35
40.0	-0.95
60.0	-0.65
80.0	-0.37

B = C<sub>4</sub>H<sub>10</sub>O, Ethyl ether (35, 139, 168)Wt. % B | ε  
Audio; 20°C

0.0	4.36
20.0	5.85
40.0	5.83
60.0	5.36
80.0	4.81
100.0	4.44

B = C<sub>5</sub>H<sub>10</sub>, Amylene (42)

Audio; 21.2°C

10.0	4.44
20.0	3.92
40.0	3.08
60.0	2.61
80.0	2.28

B = C<sub>5</sub>H<sub>12</sub>, Pentane (42)

Audio; 21.7°C

10.0	4.39
20.0	3.77
40.0	2.89
60.0	2.39
80.0	2.10

B = C<sub>6</sub>H<sub>6</sub>, Benzene (42)

Audio; 19°C

20.0	3.97
30.0	3.66
50.0	3.22
70.0	2.83
90.0	2.29

B = C<sub>7</sub>H<sub>16</sub>, Heptane (42)Wt. % B | ε  
Audio; 20.2°C

0.0	5.10
20.0	3.87
40.0	3.03
60.0	2.47
80.0	2.18

B = C<sub>7</sub>H<sub>16</sub>O, Ethyl amyl ether (42)

Audio; 23.3°C

0.0	4.97
10.0	5.29
30.0	5.34
50.0	5.03
80.0	3.90
100.0	3.56

B = Oleates; see Table 9

CH<sub>4</sub>N<sub>2</sub>O

Urea

B = CH<sub>4</sub>O, Methyl alcohol (174)M % A | ε  
4 × 10<sup>3</sup>; 22.1°C  
10.4 | 44 ± 1B = C<sub>2</sub>H<sub>5</sub>O, Ethyl alcohol (174)4 × 10<sup>3</sup>; 22.0°C  
4.0 | 25.0 ± 0.5CH<sub>4</sub>O

Methyl alcohol

B = C<sub>3</sub>H<sub>7</sub>NO<sub>2</sub>,

Urethane (174)

M % B | ε  
4 × 10<sup>3</sup>; 21.6°C  
55.5 | 18.0 ± 0.5B = C<sub>6</sub>H<sub>6</sub>, Benzene (139)Wt. % B | ε  
Audio; 16°C

95.0	2.96*
96.0	2.80
97.0	2.66
99.0	2.37

B = C<sub>7</sub>H<sub>8</sub>, Toluene (139)

Audio; 16°C

96.0	2.87*
97.0	2.75
98.0	2.62
99.0	2.49

B = C<sub>8</sub>H<sub>9</sub>NO, Acetanilide (174)M % B | ε  
4 × 10<sup>3</sup>; 22.2°C  
10.5 | 37.0 ± 1.0B = C<sub>10</sub>H<sub>8</sub>, Naphthalene (174)4 × 10<sup>3</sup>; 22.1°C

1.8 | 30.0 ± 1.0

C<sub>2</sub>H<sub>3</sub>Cl<sub>3</sub>O<sub>2</sub>

Chloral hydrate

B = C<sub>2</sub>H<sub>5</sub>O, Ethyl alcohol (174)M % A | ε  
4 × 10<sup>3</sup>; 21.5°C  
51.3 | 13.0 ± 0.2B = C<sub>7</sub>H<sub>8</sub>,

Toluene (174)

4 × 10<sup>3</sup>; 21.9°C  
13.1 | 3.0 ± 0.2C<sub>2</sub>H<sub>4</sub>Br<sub>2</sub>

Ethylene bromide

B = C<sub>4</sub>H<sub>10</sub>O, Ethyl ether (42)Wt. % B | ε  
Audio; 22.0°C

20	4.94
40	4.79
60	4.64
80	4.50

B = C<sub>5</sub>H<sub>10</sub>,

Amylene (42)

Audio; 21.4°C

20	3.35
40	2.60
60	2.33
80	2.17
100	2.07

B = C<sub>6</sub>H<sub>6</sub>,

Benzene (42)

Audio; 23.1°C

20.0	3.78
60.0	2.72
80.0	2.48
100.0	2.284

B = C<sub>7</sub>H<sub>16</sub>,

Heptane (42)

Audio; 22.7°C

0	4.92
20	3.22
40	2.57
60	2.29
80	2.15

C<sub>2</sub>H<sub>5</sub>NO

Acetamide

B = C<sub>2</sub>H<sub>5</sub>O, Ethyl alcohol (174)M % A | ε  
4 × 10<sup>3</sup>; 22.0°C  
35.6 | 45.0 ± 1.0C<sub>2</sub>H<sub>6</sub>O

Ethyl alcohol

B = C<sub>3</sub>H<sub>7</sub>NO<sub>2</sub>,

Urethane (174)

M % B | ε  
4 × 10<sup>3</sup>; 21.6°C  
52.0 | 16 ± 0.5B = C<sub>4</sub>H<sub>5</sub>NO<sub>2</sub>,

Succinimide (174)

4 × 10<sup>3</sup>; 21.8°C  
2.3 | 23.0 ± 0.5B = C<sub>4</sub>H<sub>10</sub>O, Ethyl ether (105)Wt. % B | ε  
10<sup>3</sup>; 20°C

0	25.8
10	23.2
20	20.6
30	18.0
40	15.5
50	13.10
60	10.90
70	8.90
80	7.20
90	5.70
100	4.35

B = C<sub>6</sub>H<sub>6</sub>,

Benzene (105)

Audio; 20°C

0.0	25.80
10.0	23.20
20.0	20.60
30.0	18.00
40.0	15.50
50.0	13.10
60.0	10.80
70.0	8.60
80.0	6.50
90.0	4.30
100.0	2.28

B = C<sub>6</sub>H<sub>4</sub>O<sub>2</sub>,

Resorcinol (174)

M % B | ε  
4 × 10<sup>3</sup>; 22.0°C  
40.3 | 11.5 ± 0.5B = C<sub>7</sub>H<sub>8</sub>,

Toluene (139)

Wt. % B | ε  
Audio; 16°C

96.0	2.67*
97.0	2.59
98.0	2.51

B = C<sub>7</sub>H<sub>9</sub>N,

p-Toluidine (174)

M % B | ε  
4 × 10<sup>3</sup>; 21.7°C  
50.0 | 10.0 ± 0.5B = C<sub>8</sub>H<sub>9</sub>NO,

Acetanilide (174)

4 × 10<sup>3</sup>; 21.8°C  
9.4 | 29.0 ± 0.5B = C<sub>10</sub>H<sub>8</sub>,

Naphthalene (174)

4 × 10<sup>3</sup>; 21.5°C  
3.3 | 22.0 ± 0.5C<sub>3</sub>H<sub>6</sub>O

Acetone

B = C<sub>6</sub>H<sub>6</sub>,

Benzene (49)

Wt. % B | ε  
4 × 10<sup>3</sup>; 20°C  
0.0 | 20.5\*

20.0 | 16.8

B = C<sub>6</sub>H<sub>6</sub>.— (Continued)

Wt. % B | ε

60.0	8.49
80.0	3.59
100.0	2.28
Wt. % B	δ <sub>20</sub>
0.0	-12.36
20.0	-8.80
40.0	-3.41
80.0	-1.08
100.0	-0.23

B = C<sub>7</sub>H<sub>8</sub>, Toluene (5)Wt. % B | ε  
5 × 10<sup>3</sup>; 17°C

20.0	16.9
40.0	13.1
60.0	9.48
80.0	3.97

C<sub>3</sub>H<sub>7</sub>NO<sub>2</sub>

Urethane

B = C<sub>3</sub>H<sub>5</sub>O,

Propyl alcohol (174)

M % A | ε  
4 × 10<sup>3</sup>; 20.9°C  
52.5 | 15.5 ± 0.5B = C<sub>7</sub>H<sub>8</sub>,

Toluene (174)

4 × 10<sup>3</sup>; 21.7°C  
19.2 | 3.0 ± 0.2C<sub>3</sub>H<sub>8</sub>O

Propyl alcohol

B = C<sub>6</sub>H<sub>6</sub>, Benzene (139)Wt. % B | ε  
Audio; 16°C

30.0	13.76*
50.0	9.82
70.0	5.975
80.0	4.05

B = C<sub>10</sub>H<sub>8</sub>, Naphthalene (174)M % B | ε  
4 × 10<sup>3</sup>; 22.0°C  
3.8 | 18.0 ± 0.5C<sub>4</sub>H<sub>8</sub>O<sub>2</sub>

Ethyl acetate

B = C<sub>6</sub>H<sub>6</sub>, Benzene (116)M % B | ε  
Audio; 20°C

0.0	6.235*
20.0	5.54
50.0	3.22
80.0	2.90
100.0	2.278

C<sub>4</sub>H<sub>10</sub>O

Ethyl ether

B = C<sub>5</sub>H<sub>12</sub>,

Pentane (42)

Wt. % B	ε
Audio; 20.7°C	
20	3.87
40	3.08
60	2.56
80	2.17
100	1.84

B = C<sub>6</sub>H<sub>6</sub>, Benzene (139)

Audio; 18°C

0.0	4.278*
20	3.86
40	3.45
60	3.05
80	2.67

Audio; 17.8°C (42)

20	4.12
40	3.66
60	3.20
80	2.73

B = C<sub>10</sub>H<sub>7</sub>Br, α-Bromonaphthalene (42)

Audio; 19.6°C

30.0	4.60
50.0	4.87
70.0	5.03
80.0	5.04
90.0	4.98
100.0	4.912

C<sub>4</sub>H<sub>10</sub>O

Isobutyl alcohol

B = C<sub>8</sub>H<sub>10</sub>, m-Xylene (91)Wt. % B | ε  
13.25°C

40.0	10.8*
50.0	8.82
80.0	3.40

C<sub>5</sub>H<sub>5</sub>N

Pyridine; see Table 9

C<sub>5</sub>H<sub>11</sub>Cl

Amyl chloride

B = C<sub>5</sub>H<sub>10</sub>, m-Xylene (91)Wt. % B | ε  
16.4°C

40.0	4.55*
60.0	3.8
80.0	3.1



**C<sub>5</sub>H<sub>12</sub>O**  
Amyl alcohol  
B = C<sub>6</sub>H<sub>6</sub>,  
Benzene (139)  
Wt. % B |  $\epsilon$   
Audio; 16°C

76.0	3.31*
80.0	3.04
88.0	2.65
92.0	2.54
96.0	2.41

B = C<sub>8</sub>H<sub>10</sub>,  
*m*-Xylene (91)  
14°C

30.0	10.7*
40.0	6.75
70.0	4.05
80.0	3.20

**C<sub>6</sub>H<sub>5</sub>Br**  
Bromobenzene  
B = C<sub>6</sub>H<sub>6</sub>,  
Benzene (42)  
Wt. % B |  $\epsilon$   
Audio; 22.35°C

20.0	4.53
40.0	3.75
60.0	3.12
80.0	2.62

**C<sub>6</sub>H<sub>5</sub>Cl**  
Chlorobenzene  
B = C<sub>7</sub>H<sub>16</sub>,  
Heptane (42)  
Wt. % B |  $\epsilon$   
Audio; 22.4°C

20.0	4.65
40.0	3.73
60.0	3.20
80.0	2.41
100.0	1.97

B = C<sub>7</sub>H<sub>16</sub>O, Ethyl  
amyl ether (42)  
Audio; 22.35°C

20.0	5.33
40.0	4.88
60.0	4.42
80.0	3.98
100.0	3.55

B = C<sub>8</sub>H<sub>10</sub>,  
*m*-Xylene (42)  
Wt. % A |  $\epsilon$   
Audio; 20.2°C

10.0	2.60
30.0	3.20
50.0	3.78
80.0	4.68

B = C<sub>8</sub>H<sub>10</sub>.—  
(Continued)  
Vol. % A |  $\epsilon$   
Audio; 15°C (16)

0.0	2.37
20.0	3.10
60.0	4.53
100.0	5.98

**C<sub>6</sub>H<sub>5</sub>NO<sub>2</sub>**  
Nitrobenzene  
B = C<sub>6</sub>H<sub>6</sub>,  
Benzene (139)  
Wt. % B |  $\epsilon$   
Audio; 16°C

0.0	37.93*
20.0	24.10
40.0	16.70
60.0	9.55
80.0	5.50
100.0	2.291

B = C<sub>6</sub>H<sub>11</sub>N,  
Capronitrile (99)  
4 × 10<sup>8</sup>; 23°C

50.0	19.6
60.0	18.1
70.0	17.1

B = C<sub>7</sub>H<sub>8</sub>,  
Toluene (139)  
Audio; 16°C

0.0	37.92*
20.0	25.7
40.0	17.2
80.0	5.7
100.0	2.39

B = Oleates; see  
Table 9

**C<sub>6</sub>H<sub>6</sub>**  
Benzene  
B = C<sub>6</sub>H<sub>6</sub>O,  
Phenol (140)  
Wt. % B |  $\epsilon$   
Audio; 20°C

5.0	2.33
15.0	2.88
25.0	3.63

B = C<sub>7</sub>H<sub>8</sub>,  
Toluene (77)  
10<sup>6</sup>; 20°C

20.0	2.277
40.0	2.287
60.0	2.296
80.0	2.324

Wt. % B |  $\epsilon$   
(10 t 75)

20.0	— 0.14
40.0	— 0.14
60.0	— 0.125
80.0	— 0.12

B = C<sub>7</sub>H<sub>8</sub>O,  
*o*-Cresol (140)  
Wt. % B |  $\epsilon$   
Audio; 20°C

5.0	2.83
10.0	2.57
15.0	2.73
25.0	3.04

B = C<sub>7</sub>H<sub>8</sub>O,  
*m*-Cresol (140)  
Audio; 20°C

5.0	2.44
15.0	2.87
20.0	3.12

B = C<sub>7</sub>H<sub>8</sub>O,  
*p*-Cresol (140)  
Audio; 20°C

5.0	2.44
10.0	2.67
20.0	3.16
25.0	3.40

B = C<sub>7</sub>H<sub>8</sub>O, Phenyl  
methyl ether (140)  
Audio; 20°C

5.0	2.39
15.0	2.57
25.0	2.64

B = C<sub>8</sub>H<sub>10</sub>O,  
*o*-Tolyl methyl  
ether (140)  
Audio; 20°C

5.0	2.355
15.0	2.48
25.0	2.59

B = C<sub>8</sub>H<sub>10</sub>O,  
*m*-Tolyl methyl  
ether (140)  
Audio; 20°C

5.0	2.37
15.0	2.53
25.0	2.68

B = C<sub>8</sub>H<sub>10</sub>O,  
*p*-Tolyl methyl  
ether (140)  
Audio; 20°C

5.0	2.365
15.0	2.51
25.0	2.665

B = C<sub>10</sub>H<sub>16</sub>O,  
Camphor (54)  
4 × 10<sup>8</sup>; 24.0°C

0.00	2.27
5.00	2.53
10.0	2.94
15.0	3.54
20.0	4.60
25.0	6.02

B = C<sub>10</sub>H<sub>20</sub>O,  
Menthol (54)  
Wt. % B |  $\epsilon$   
4 × 10<sup>8</sup>; 23°C

0.00	2.26
5.00	2.59
15.0	3.54
25.0	4.58

B = Oleates; see  
Table 9

B = Castor Oil  
(185)  
Audio; 20°C

10.0	2.55*
20.0	2.76
30.0	2.85
40.0	3.09
50.0	3.44
60.0	3.62
70.0	4.06
80.0	4.22
90.0	4.59

Wt. % B |  $\epsilon$   
 $\partial_{20}$

30.0	— 0.09
40	— 0.20
50	— 0.33
60	— 0.45
70	— 0.58
80	— 0.70
90	— 0.93

**C<sub>6</sub>H<sub>6</sub>O**  
Phenol  
B = C<sub>8</sub>H<sub>10</sub>,  
*m*-Xylene (140)  
Wt. % A |  $\epsilon$   
Audio; 20°C

5.0	2.57
15.0	2.87
25.0	3.16

**C<sub>6</sub>H<sub>7</sub>N**  
Aniline  
B = C<sub>8</sub>H<sub>10</sub>,  
*m*-Xylene (100)  
Wt. % B |  $\epsilon$   
4 × 10<sup>8</sup>; 18°C

0.0	6.50*
20.0	5.63
60.0	3.93
80.0	3.19
100.0	2.44

**C<sub>6</sub>H<sub>11</sub>N**  
Capronitrile; see  
Table 9

**C<sub>7</sub>H<sub>8</sub>**  
Toluene  
B = C<sub>7</sub>H<sub>16</sub>,  
Heptane (42)  
Wt. % B |  $\epsilon$   
Audio; 21.1°C

20.0	2.285
40.0	2.215

B = C<sub>7</sub>H<sub>16</sub>.—  
(Continued)  
Wt. % B |  $\epsilon$

60.0	2.146
80.0	2.075

B = C<sub>9</sub>H<sub>10</sub>O<sub>2</sub>,  
Ethyl benzoate  
(116)  
M % B |  $\epsilon$   
Audio; 20°C

0.0	2.387
40.0	3.35
60.0	3.84
80.0	4.33
100.0	4.915

B = C<sub>10</sub>H<sub>8</sub>,  
Naphthalene (174)  
4 × 10<sup>8</sup>; 22.6°C

22.5	2.8 ± 0.2
------	-----------

B = C<sub>10</sub>H<sub>16</sub>,  
Turpentine (116)  
Audio; 20°C

0.0	2.39*
20.0	2.23
60.0	2.22
80.0	2.20
100.0	2.19

B = C<sub>12</sub>H<sub>10</sub>,  
Acenaphthene (174)  
4 × 10<sup>8</sup>; 22.0°C

15.4	2.8 ± 0.2
------	-----------

B = C<sub>14</sub>H<sub>10</sub>,  
Phenanthrene (174)  
4 × 10<sup>8</sup>; 21.7°C

21.0	2.3 ± 0.2
------	-----------

B = Petroleum  
(170)

Wt. % B |  $\epsilon$   
Audio; 11°C

0.0	2.70*
20.0	2.55
40.0	2.47
60.0	2.37
80.0	2.21
100.0	2.08

Audio; 21°C

0.0	2.55*
20.0	2.44
40.0	2.34
60.0	2.27
80.0	2.15
100.0	2.04

B = Castor oil (170)  
Audio; 20°C

0.0	2.56
20.0	2.94
40.0	3.38
60.0	3.71
80.0	4.21
100.0	4.61

**C<sub>7</sub>H<sub>8</sub>O**  
Phenyl methyl ether  
B = C<sub>8</sub>H<sub>10</sub>,  
*m*-Xylene (140)  
Wt. % B |  $\epsilon$   
Audio; 20°C

75.0	2.79
85.0	2.63
95.0	2.47

**C<sub>7</sub>H<sub>16</sub>**  
Heptane  
B = C<sub>10</sub>H<sub>7</sub>Br,  
 $\alpha$ -Bromonaphthalene (42)  
Wt. % B |  $\epsilon$   
Audio; 20.8°C

40	2.63
50	2.84
70	3.42
80	3.87

**Petroleum**  
B = C<sub>10</sub>H<sub>16</sub>,  
Turpentine (6)  
Wt. % B |  $\epsilon$   
Audio; 20°C

0	2.03
20	2.08
40	2.11
60	2.16
80	2.20
100	2.27

Wt. % B |  $\epsilon$   
 $\partial_{20}$

0	— 0.20
20	— 0.31
40	— 0.60
60	— 0.80
80	— 0.91
100	— 0.96

B = Castor oil (6)  
Wt. % B |  $\epsilon$   
Audio; 20°C

0	2.03
20	2.60
40	2.93
60	3.40
80	3.93
100	4.46

Wt. % B |  $\epsilon$   
 $\partial_{20}$

0	— 0.20
20	— 0.20
40	— 0.80
60	— 2.86
80	— 3.01
100	— 3.77

**Cottonseed oil**  
See Table 9

**Kerosene**  
See Table 9



TABLE 9.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF SOLUTIONS OF THE OLEATES OF THE HEAVY METALS

Solvents: (1)  $\text{CCl}_4$ , Carbon tetrachloride; (2)  $\text{CS}_2$ , Carbon disulfide; (3)  $\text{CHCl}_3$ , Chloroform; (4)  $\text{C}_5\text{H}_5\text{N}$ , Pyridine; (5)  $\text{C}_6\text{H}_5\text{NO}_2$ , Nitrobenzene; (6)  $\text{C}_6\text{H}_6$ , Benzene; (7)  $\text{C}_6\text{H}_{11}\text{CN}$ , Capronitrile; (8) Cottonseed oil; (9) Kerosene. All values of  $\epsilon$  have been recalculated to accord with the values given in Table 1.  $\nu = 4 \times 10^3$ ;  $C$  = concentration of the oleate of the metal named in first column. Unit of  $C$  = 1% by weight; of  $\epsilon$  = 1 cgse;  $t$  = centigrade temperature,  $^\circ\text{C}$ .

	(1) $\text{CCl}_4$ (99)			(2) $\text{CS}_2$ (99)			(3) $\text{CHCl}_3$ (42)		
	$C$	$t$	$\epsilon$	$C$	$t$	$\epsilon$	$C$	$t$	$\epsilon$
Al.....	50	17.0	2.17	50.0	19.0	2.42	50.0	24.0	3.38
Cd.....				2.0	22.0	2.92	2.0	19.0	4.34
Co.....	8	17.0	2.17	4.0	24.0	2.67	10.0	20.0	4.24
Cr.....	4	19.0	2.29						
Cu.....	15	19.0	2.17	15.0	24.0	2.54	15.0	19.0	4.39
Fe.....	4	20.0	2.17	5.0	24.0	2.72	8.0	20.0	4.34
Mg.....	8	19.0	2.07						
Mn.....	6	19.0	2.02	2.0	19.0	2.72	15.0	20.0	4.34
Ni.....	15	19.0	2.26	15.0	24.0	2.57	15.0	19.0	4.66
Zn.....	15	19.0	2.23				15.0	20.0	4.39

	(4) $\text{C}_5\text{H}_5\text{N}$ (99)			(5) $\text{C}_6\text{H}_5\text{NO}_2$ (99)			(6) $\text{C}_6\text{H}_6$ (99)		
	$C$	$t$	$\epsilon$	$C$	$t$	$\epsilon$	$C$	$t$	$\epsilon$
Al.....	50	25.5	7.36	50	22.0	13.1	50	17.0	2.62
Cd.....	8	25.0	11.0				5	19.5	2.23
Co.....	10	24.0	11.9				25	20.0	2.37
Cu.....	20	24.0	10.8	10	21.0	24.5	20	19.5	2.07
Fe.....	10	24.0	12.0				10	20.0	2.07
Mg.....	15	25.0	11.7				20	20.0	2.27
Mn.....	15	25.5	9.88				10	20.0	2.17
Ni.....	25	24.0	10.1	10	22.0	25.9	20	19.5	2.37
Zn.....	25	24.0	10.3				25	20.0	2.02

	(7) $\text{C}_6\text{H}_{11}\text{CN}$ (99)			(8) Cottonseed oil (99)			(9) Kerosene (99)		
	$C$	$t$	$\epsilon$	$C$	$t$	$\epsilon$	$C$	$t$	$\epsilon$
Al.....	30	18.0	10.9	50	20.0	2.30	50	20.0	1.26
Cu.....	10	18.0	13.4	10	20.0	2.40	5	20.0	1.51
Fe.....	5	18.0	13.3						
Mg.....	5	18.0	13.5	5	20.0	2.65	5	20.0	1.21
Mn.....				10	20.0	2.67	5	19.5	1.41
Ni.....	10	18.0	13.3				5	20.0	1.26
Zn.....	10	18.0	12.8	15	20.0	2.57	8	20.0	1.21

TABLE 10.—DIELECTRIC CONSTANT ( $\epsilon$ ) OF SOLUTIONS AT TEMPERATURES BELOW  $-100^\circ\text{C}$ 

## Aqueous Solutions

Concentration (=weight % of solute) is stated in center of column. Centigrade temperatures

<b>B = <math>\text{H}_2\text{SO}_4</math> (67)</b>		<b>B = <math>\text{PbO} + x\text{KOH}</math> (39)</b>		<b>B = <math>(\text{NH}_4)_2\text{MoO}_4</math> (39)</b>		<b>B = <math>\text{NaClO}_4</math> (39)</b>		<b>B = <math>\text{Na}_2\text{SO}_4</math> (39)</b>		<b>B = <math>\text{Na}_2\text{B}_4\text{O}_{10} \cdot 10\text{H}_2\text{O}</math> (39)</b>		<b>B = <math>\text{K}_2\text{CrO}_4</math> (39)</b>	
$-t$	$\epsilon$	$-t$	$\epsilon$	$-t$	$\epsilon$	$-t$	$\epsilon$	$-t$	$\epsilon$	$-t$	$\epsilon$	$-t$	$\epsilon$
10% B		B = $\text{Pb}(\text{NO}_3)_2$ (39)		10% B		10% B		10% B		15% B		36% B	
140	8.1	B = $\text{CuSO}_4$ (67)		80	96.5	90	10.0	100	12.8	100	19.5	100	19.5
150	5.3	$-t$		110	91.6	120	8.6	120	10.5	120	14.5	120	14.5
170	4.1	10% B		140	84.0	150	7.0	140	92.2	140	13.2	140	13.2
180	4.1	110				170	7.2	160	87.8	160	12.8	160	12.8
<b>B = <math>\text{NH}_4\text{OH}</math> (67)</b>		120				180	6.9	170	83.9	180	11.1	180	11.1
34.94% B		130						180	71.0	<b>B = <math>\text{K}_2\text{Al}_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}</math> (39)</b>		9% B	
140	36.0	140				<b>B = <math>\text{NaHSO}_4</math> (39)</b>		0.05% B		120		32.5	
150	10.7	140				10% B		120		130		24.4	
160	5.1	160				150	15.2	130		140		14.4	
170	4.5	170				170	8.9	140		150		6.8	
		180				180	5.7	170		170		3.4	
		180						180		180			
		180						190		190			



B = RbOH (39)		B = RbOH.— (Cont'd)		B = CsOH (39)	
-t	ε	-t	ε	-t	ε
5% B				2.85% B	
130	20 <sub>9</sub>	170	19 <sub>5</sub>	140	3.3 <sub>2</sub>
150	20 <sub>4</sub>	180	17 <sub>6</sub>	170	2.8 <sub>0</sub>
160	20 <sub>1</sub>	184	13 <sub>9</sub>	190	2.7 <sub>6</sub>
		188	80.0		

Alcoholic Solution; Solvent = C<sub>2</sub>H<sub>5</sub>O; B = KOH (67)

5% B	-t =	170	175	180	185	190
	ε =	4.00	3.1 <sub>3</sub>	2.8 <sub>2</sub>	2.7 <sub>0</sub>	2.6 <sub>2</sub>

TABLE 11.—DIELECTRIC CONSTANT (ε) OF COLLOIDAL SUSPENSIONS IN WATER

Frequency of emf =  $\nu = A \times 10^3$  cycle/sec; concentration = C, unit of C = 1 gram per 100 kg of mixture = 1 g per 10<sup>5</sup> g; centigrade temperature. For Au, S, Al<sub>2</sub>O<sub>3</sub>, Bi<sub>2</sub>O<sub>3</sub>, CuO, CuCO<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, PbO, v. (39).

V<sub>2</sub>O<sub>5</sub> (59)

A	n	ε	A	n	ε	t	ε
C = 0.75; 19°C			C = 8; 20.0°C (57)			C = 49; A = 6.82; n = 5 (56)	
2.5	3	131	5.45	4	720	20.0	127.7
5.0	3	131	6.7	4	610	30.0	85.9
6.0	3	130	8.57	4	450	45.0	81.3
7.5	3	126	1.2	5	304		
1.5	4	113	3	5	155		
C = 3; 19°C			C = 32; 20°C (57)			C = 120; 20.0°C (57)	
1.5	3	335	3	5	225	3.0	390
1.875	3	350	3.75	5	180	3.75	306
2.5	3	355	6.0	5	125	6.0	187
3.0	3	350	1	6	94	1	125
5.0	3	340					
1.5	4	257					
C = 6; 19°C			C = 32; A = 6.00; n = 5 (57)			C = 120; A = 6.0; n = 5 (57)	
2.5	3	527	20.0	146		30.0	172
3.75	3	569	40.0	115		40.0	126
5.0	3	550	50.0	95.5		50.0	102
7.5	3	505	60.0	78.0		60.0	78.4
1.5	4	410	70.0	75.0			

TABLE 12.—DIELECTRIC CONSTANT (ε) OF MISCELLANEOUS MATERIALS

	ε	Lit.
Basalt*	12	(120)
Diorite*	8 to 9	(120)
Granite*	7 to 9	(120)
Loam (dry)†	3.5	(200)
Melaphyre*	13	(120)
Sand (dry)†	2.5	(200)
Sand (15% H <sub>2</sub> O)†	ca. 9	(200)
Sandstone*	9 to 11	(120)
Sidot blende†		
In dark	7.2	
Illuminated	14.4	
Soil (dry)‡	1.9	(200)
Soil (19% H <sub>2</sub> O)‡	ca. 8	(200)

\* Dried in desiccator for 10 hr.

† Observations made at radio frequency.

‡ Phosphorescent ZnS, contains Cu (<0.01% Cu). For variation of ε with intensity and wave-length of illumination, see (78); with frequency of emf, see Molthan, *Zeits. f. Physik*, 4: 262; 1921. 5: 284; 1921; with temperature and with phosphorescence, see Wilde, *Zeits. f. Physik*, 15: 350; 1923.

§ "Garden soil."

TABLE 13.—VARIATION OF DIELECTRIC CONSTANT (ε) WITH PRESSURE: PURE ORGANIC LIQUIDS AND SOLID C<sub>6</sub>H<sub>6</sub>  
 $\epsilon_p = \epsilon_0(1 + ap \times 10^{-4} + bp^2 \times 10^{-8})$  if  $1 < p < p_m$ ;  $\epsilon_p = \epsilon_0(1 + 0.01\Delta p)$  where  $p$  has the value given in the table.  $\epsilon_0$  = value of ε at 20°C and 1 atmosphere,  $\epsilon_p$  is its value at 20°C and a pressure of  $p + 1$  atm. For values of  $\epsilon_0$ , see Table 4. Unit of  $p$ ,  $p_m$  = 1 normal atmosphere.

		p	Δp	a	b	p <sub>m</sub>	Lit.
CCl <sub>4</sub>	Carbon tetrachloride	100	0.67	0.72	-4	60	(75.1)
		300	1.93				(68.1)
		500	3.04				(68.1)
		800	4.47	0.68	-1.5	800	(68.1)
CHCl <sub>3</sub>	Chloroform	500	4.95	1.00	-5	58	(75.1)
				1.120	-2.6	500	(136)
CH <sub>3</sub> O	Methyl alcohol	200	2.0 <sub>8</sub>				(64)
C <sub>2</sub> H <sub>5</sub> O	Ethyl alcohol, 99.8 %	200	2.0 <sub>1</sub>				(64)
C <sub>3</sub> H <sub>6</sub> O	Acetone	200	2.9 <sub>9</sub>				(64)
C <sub>4</sub> H <sub>10</sub> O	Ether			2.374	-19	60	(75.1)
		500	9.39	2.260	-7.62	500	(136)
C <sub>5</sub> H <sub>12</sub> O	Amyl alcohol	100	0.42				(145)
		300	1.27				(145)
C <sub>6</sub> H <sub>5</sub> Br	Bromobenzene			0.620	0	60	(75.1)
C <sub>6</sub> H <sub>5</sub> NO <sub>2</sub>	Nitrobenzene			0.640	0	58	(75.1)
C <sub>6</sub> H <sub>6</sub>	Benzene	100	0.59 <sub>8</sub>	0.64 <sub>5</sub>	-5.0	120	(188)
		100	0.52 <sub>8</sub>				(68.1)
		300	1.48				(68.1)
		500	2.38				(68.1)
		500	2.6 <sub>6</sub>	0.62 <sub>8</sub>	-1.7 <sub>5</sub>	500	(136)
		700	3.08	0.55	-1.4	700	(68.1)
	(solid, 11°C)	>300		0.34	0	850	(68.1)
C <sub>6</sub> H <sub>7</sub> N	Aniline	100	0.45				(145)
		300	1.3 <sub>8</sub>				(145)
C <sub>6</sub> H <sub>14</sub>	Hexane	100	0.80 <sub>6</sub>	0.89 <sub>0</sub>	-8.3 <sub>8</sub>	120	(188)
		100	0.77				(68.1)
		300	2.17				(68.1)
		500	3.37				(68.1)
		800	4.80	0.79	-2.4	800	(68.1)
C <sub>7</sub> H <sub>7</sub> NO <sub>2</sub>	o-Nitrotoluene			0.667	0	60	(75.1)
C <sub>7</sub> H <sub>8</sub>	Toluene			0.60 <sub>8</sub>	-2	60	(75.1)
		500	2.8 <sub>1</sub>	0.614	-1.0 <sub>5</sub>	500	(136)
C <sub>7</sub> H <sub>16</sub>	Heptane	100	0.72				(68.1)
		300	2.0 <sub>1</sub>				(68.1)
		500	3.09				(68.1)
		800	4.30	0.74	-2.5	800	(68.1)
C <sub>8</sub> H <sub>10</sub>	m-Xylene	500	2.6 <sub>5</sub>	0.65 <sub>1</sub>	-2.3 <sub>8</sub>	500	(136)

TABLE 14.—EFFECT OF MAGNETIC FIELD (H) UPON THE DIELECTRIC CONSTANT (ε) (94)

In general, ε is independent of H; but for certain liquid crystals, changes have been observed. The available data are given in this table.  $\parallel[\perp]$  denotes that the direction of H is parallel [perpendicular] to the direction of the electrical field used to determine ε;  $\epsilon_0$  = value of ε when H = 0.  $\epsilon_H = \epsilon_0(1 + 0.01\Delta)$ . Unit of H = 1 kilogauss = 1000 cgsm unit; of ε = 1 cgse unit.

Substance	t	H	-Δ <sub>  </sub>	ε <sub>0</sub>
CHCl <sub>3</sub>				
(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> O	20°	11.0	<0.1	1.47
C <sub>6</sub> H <sub>5</sub> NO <sub>2</sub>	20°	25.0	<0.03	5.14
C <sub>6</sub> H <sub>6</sub>	20°	25.0	<0.03	4.36
C <sub>6</sub> H <sub>5</sub> NH <sub>2</sub>	20°	25.0	<0.016	35.6
	20°	25.0	<0.06	2.28
	20°	25.0	<0.02	7.13
C <sub>14</sub> H <sub>14</sub> N <sub>2</sub> O <sub>2</sub> , p-Azoxyanisole (liquid crystal) ε <sub>0</sub> = 6.9				
H	-Δ <sub>  </sub>	-Δ <sub>  </sub>	-Δ <sub>⊥</sub>	
0.30	122°	135°	122°	
0.50	1.4	0.0		
1.00	2.2			
2.00	2.7	0.2		
4.00	2.8	0.8	0.0	
7.35	2.8	0.3		
C <sub>16</sub> H <sub>18</sub> N <sub>2</sub> O <sub>2</sub> , p-Azoxypheenetole (liquid crystal) ε <sub>0</sub> = 6.8				
H	-Δ <sub>  </sub>	-Δ <sub>  </sub>	-Δ <sub>⊥</sub>	
0.15	143°	154°	143°	
0.30	0.4	0.6		
0.50	1.1			
1.00	3.0	2.2		
2.00	4.8	4.0		
4.00	5.0			
7.35	5.4	4.8	0.0	
	5.7	4.9		



TABLE 15.—EFFECT OF ELECTRIC FIELD ( $E$ ) UPON THE DIELECTRIC CONSTANT ( $\epsilon$ ) (84, 144)

Data bearing upon this effect are discordant and of doubtful value

$$\epsilon_{E_1} = 4\pi \left( \frac{\partial D}{\partial E} \right)_{E=E_1}, \text{ and } \epsilon_0 = 4\pi \left( \frac{\partial D}{\partial E} \right)_{E=0}$$

Unit of  $\nu$  = 1 cycle/sec; of  $E$  = 1 cgse unit; of  $\epsilon_{E_1}$ ,  $\epsilon_0$  = 1 cgse unit. Centigrade temperature.

	$t$	$\nu$	$E_1$	$\epsilon_0 - \epsilon_{E_1}$	Lit.
$C_6H_{11}OH + C_6H_6^*$	19°	3000	20	0.018	(144)
$\epsilon_0 = 3.089$		3000	30	0.047	(144)
		10 <sup>6</sup>	160	$< 1 \times 10^{-6}$	(84)
$(C_2H_5)_2O$ , Ether	20°	10 <sup>6</sup>	100	$7 \times 10^{-6}$	(84)

\* Solution of *n*-amyl alcohol ( $C_6H_{11}OH$ ) in benzene ( $C_6H_6$ ); concentration = 20 vol. % of  $C_6H_{11}OH$ .

TABLE 16.—DIELECTRIC STRENGTH ( $S$ ) OF PURE ORGANIC SUBSTANCES

The dielectric strength ( $S$ ) of a substance is defined as the minimum value of the electrical field intensity, in the substance, which will cause a disruptive electric discharge.

Whether it can be regarded as a constant, characteristic of the substance, is doubtful; it appears to vary with the nature of the electrodes, and with the sparking distance. If the distance is very short as compared with the radii of curvature of the faces of the electrodes, the field is essentially uniform and  $S = V_s/l$ , where  $V_s$  is sparking potential corresponding to the distance  $l$ . For greater distances, the field is not uniform and  $S$  is the maximum value of the field intensity. The available data are given in this table; probably all are uncertain by at least  $\pm 5\%$ . Unit of  $l$  = 1 mm = 0.1 cm; of  $V_s$  = 1 volt; of  $S$  = 10<sup>6</sup> volt/cm.

Formula	Substance		$l$	$V_s$	$S$	Lit.
$C_5H_{12}$	Pentane.....	A*	0.001	110	1.10	(169)
			0.002	220	1.10	(169)
			0.003	330	1.10	(169)
$C_6H_{14}$	Hexane.....	A*	0.001	62	0.62	(169)
			0.002	195	0.98	(169)
			0.0025	316	1.26	(169)
$C_7H_{16}$	Heptane.....	A*	0.001	100	1.00	(169)
			0.002	186	0.93	(169)
			0.003	300	1.00	(169)
$C_8H_{18}$	Octane.....	A*	0.001	96	0.96	(169)
			0.002	190	0.95	(169)
			0.003	285	0.95	(169)
$C_6H_6$	Benzene.....	B*	0.5	32 500	0.65	(4)
$C_6H_4(CH_3)_2$	<i>o</i> -Xylene.....	B*	0.3	24 000	0.80	(4)
			0.4	28 100	0.70	(4)
			0.5	32 000	0.64	(4)
			0.6	36 100	0.60	(4)
		C*	0.2	22 200	1.11	(4)
			0.3	28 500	1.05	(4)
			0.4	34 800	1.01	(4)
			0.5	41 000	0.97	(4)
$C_6H_5NH_2$	Aniline 5%, in benzene.....	B*	0.45	29 000	0.64	(4)

\* A = Electrodes of iridio-platinum; one flat, one spherical, radius great. B = Electrodes are brass spheres, diameter = 2 cm. C = Electrodes are brass spheres, diameter = 0.2 cm.

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## HIGH VOLTAGE CORONA

J. B. WHITEHEAD

**Introduction.**—With alternating voltage the corona first appears at the crest of the voltage wave. For oscillographic study of effect of corona on current wave,  $v$ . (2). The formation of corona in a closed cylindrical tube is followed by a rise in pressure; Kunz (13), Warner (34), and Fazel (8) ascribe this to generation of new ions; Arnold (1) and Tyndall (33) ascribe it to a rise in temperature. Corona phenomenon finds a practical application in the corona voltmeter (43) for measuring high voltages; the corona rod and coaxial cylinder are enclosed in an airtight casing in which the pressure may be varied so as to extend the range; corona formation is indicated by ionization current or by sound in telephone; accuracy is 0.5%.

**Symbols.**— $E_{mc}$  = maximum electric field (potential gradient) at surface of conductor when corona first appears;  $k$  = empirical constant;  $p$  = pressure,  $r$  = radius of conductor,  $s$  = distance between centers of adjacent conductors,  $t$  = temperature ( $^{\circ}\text{C}$ ),  $V_{ac}[V_{mc}]$  = effective [maximum] potential of conductor above neutral when corona first appears,  $V_e$  = effective potential of conductor above neutral,  $W_{ic}$  = power loss due to corona,  $\delta$  = ratio of density of air to its value at  $25^{\circ}\text{C}$  and 1 atmosphere (if unit of  $p = 1$  cm of Hg,  $\delta = 3.92p/(273 + t)$ ),  $\nu$  = frequency.

**General Relations.**—For round wires in air  $E_{mc} = A\delta + B\sqrt{\delta/r}$ ;  $A$  and  $B$  depend somewhat upon frequency ( $\nu$ , Tables 1, 2). For He, H, O, and N, Lee and Kurrelmeyer find  $E_{mc} = Ap + B\sqrt{p}$  if  $4$  cm Hg  $\leq p \leq 30$  cm Hg;  $A$  and  $B$  depend upon the gas (13.1).

For transmission lines and cables (23),  $V_{mc} = k\delta E_{mc}r \log_e(s/r)$ ; for smooth wires,  $k = 1$ ; for weathered wires,  $k = 0.98$  to  $0.93$ ; for 7-strand cables,  $k = 0.87$  to  $0.83$ . For power loss Peek (16, 17, 20) proposes the empirical relation:  $W_i = 241/\delta(\nu + 25)\sqrt{r/s} \times (V_e - V_{mc})^2 \times 10^{-5}$  watt per meter, where unit of  $\nu = 1$  cycle/sec, of  $V_e$ ,  $V_{mc} = 1$  kilovolt. This relation does not accord with observations if  $(V_e - V_{mc})$  is small. For greater values, up to 280 kilovolt, it accords closely with Peek's observations (19), and approximately with the observations of Faccioli (6), Merzhon (15), Hendricks (11), Harding (10), Lewis (14), and Wood (45, 46), but unpublished observations by Harding, up to 500 kilovolt, indicate considerable discordance.

TABLE 1.—CORONA ON CLEAN, ROUND WIRES IN AIR,  $25^{\circ}\text{C}$  AND 1 NORMAL ATMOSPHERE—VARIATION WITH RADIUS

For continuous (D.C.) voltage, subscripts (+, -) indicate the sign of the potential of the wire around which the corona appears.  $E_{mc}$ ,  $E_+$ ,  $E_-$  are independent of the material of the wire and of the humidity (37) of the air.  $E_{mc}$  decreases as  $\nu$  increases; at  $\nu = 90$

it is 2.4% less than at  $\nu = 20$  (43); at  $\nu = 2000$  it is 6% less than at  $\nu = 60$  (42); Peek (20) reports no change below  $\nu = 1000$ , and a small decrease from  $\nu = 1000$  to  $\nu = 30000$ . Probable accuracy is indicated in "Lit." column. For variation with density of air,  $\nu$ , Table 2. Unit of  $\nu = 1$  cycle/sec; of  $r = 1$  cm = 0.394 in.; of  $E_{mc}$ ,  $E_+$ ,  $E_- = 1$  kilovolt  $\text{cm}^{-1} = 3.335$  cgse  $\text{cm}^{-1} = 254$  kilovolt  $\text{in}^{-1}$ .

$\nu = 60$ cycle/sec			$\nu = 0$ (D.C.) (7, 22, 29, 30, 40, 44)		
$r$	$E_{mc}$	Lit.	$r$	$E_+$	$E_-$
0.01	120	(16)*	0.002	239	221
.025	86.5	3%	.003	198	187
0.05	71.36	(37, 38, 39, 41, 43)†	.004	174	166
.06	67.86		.005	156	150
.07	65.10		.006	144	140
.08	63.24		.007	134	132
.09	61.48		.008	126	125
.10	60.04		.009	121	120
.20	52.10		.01	116	116
.30	47.99		.02	93	95
.40	45.56		.03	82.5	85
.50	43.89		.04	76	79
.60	42.68		.05	71	74
0.70	41.72	(26)‡	.06	67.5	70.5
.80	41		.07	64.5	67.5
.90	40		.08	62.5	66.0
1.0	39.5		.09	60	64
2.0	35.8		.10	58	62
3.0	34.2		.130	56.9	
4.0	33.0		.239	51.3	
5.0	32.5		.625	43	
6.0	32.1		1.110	40.6	
7.0	31.7				
8.0	31.4	(31)§			
9.0	31.1				
10.0	30.8				
12.5	30.3				
15	30				

\* Peek: Parallel wires, high voltage by ratio transformation.

† Whitehead and coworkers: Concentric cylinders. High voltage is measured directly.

‡ Petersen: Concentric cylinders. Sparkover and corona.

§ Schumann: Concentric cylinders. Voltage by ratio transformation. Corona and sparkover.



TABLE 2.—CORONA ON ROUND WIRES IN AIR: VARIATION WITH DENSITY

There is general agreement that the equation  $E_{mc} = A\delta + B\sqrt{\delta/r}$  accords with the observations with alternating voltages of fixed  $\nu$  over a wide range of  $t$ ,  $p$ , and  $r$ ; and accords with observations with continuous voltages if  $p > 10$  cm Hg and  $r > 0.004$  cm. For D.C. data for smaller wires and lower pressures than those in table, and for current flow at  $E > E_{mc}$ ,  $v$ . (7, 30). Values in columns  $\delta$ ,  $r$ ,  $p$ , and  $t$  indicate the limiting values covered by the observations. Except as indicated the electrodes were coaxial cylinders. Unit of  $E_{mc} = 1$  kilovolt  $\text{cm}^{-1} = 3.335$  cgse  $\text{cm}^{-1}$ ; of  $r = 1$  cm; of  $p = 1$  cm of Hg; of  $t = 1^\circ\text{C}$ .

Alternating voltage, 60 cycle/sec

$\delta$	A	B	$r$	$p$	$t$	Lit.
0.47; 1.34	31.6	9.41	0.044; 0.237	36; 102	7; 41	(37, 38)
1.0; 1.13	29.8*	8.96*	0.01; 0.5	74; 76	-13; 22	(16)
0.7; 1.2	31	9.55	0.059; 0.953	75.5	-20; 140	(17)
0.02; 1	31	9.55	0.12; 0.25	1.7; 75	18; 24	(18)
<2.295	29.84	9.90	0.05; 0.63	25; 139	18; 26.7	(43)
>2.295	32.96	8.56				
1.016	27.5†	12.05†	0.05; 5.0	76	20	(26)
1.016	25.2†	19.15†	1.5; 5.96	76	20	(31)
1.016	33.7	8.9	0.037; 0.116	76	20	(40)

Continuous voltage

$\delta$	A <sub>+</sub>	A <sub>-</sub>	B <sub>+</sub>	B <sub>-</sub>	$r$	$p$	$t$	Lit.
0.07; 1.0		31		9.54	0.04	5.3; 76	25	(7)
1	33.7	31	8.13	9.54	0.037; 0.116	76	25	(40)
0.11; 1.0	39.8	40.2	7.32	8.41	0.026; 0.046	10; 70	6; 70	(44)
0.075; 1.0	31	31	9.55	9.55	0.057; 0.239			(22)

\* Parallel wires in free air.

† Computed by J. B. W. For (26) there was a sparkover, but no corona; for (31) there were both sparkover and corona.

TABLE 3.—EFFECTIVE CORONA VOLTAGE ( $V_{ec}$ ) FOR THREE-PHASE TRANSMISSION LINES IN TRIANGULAR ARRANGEMENT:  $25^\circ\text{C}$ , 1 NORMAL ATMOSPHERE

Corona causes an increase in electrostatic capacity of line, and in 3-phase, Y-connected grounded systems, causes a triple harmonic in the neutral; in ungrounded systems, distortion of voltage may result (24). Surface irregularities of transmission conductors reduce the corona-forming voltage. Peek (23) gives the following general equation:  $V_{ec}\sqrt{2} = V_{mc} = k\delta E_{mc}r \log_e(s/r)$ .

For symbols and values of  $k$ , see above. At  $25^\circ\text{C}$  and an altitude of  $H$  meter above sea-level,  $\delta = 1 - \Delta$ , where  $1/\Delta = 0.5 + 8730/H$ , approximately (cf. eq. 4, Vol. I, p. 71).

If all wires are in same plane,  $V_{ec}$  for central wire will be 4% lower, and for outer wires 6% higher than for triangular arrangement of same spacing. For parallel brass tubes,  $2r = 2.54$  to  $8.9$  cm,  $s = 465$  cm,  $V_{ec} = 400$  to  $990$  kilovolt, Peek (25) reports agreement with the equation.

In first column of table the numbers 4 to 0000 refer to the Brown and Sharpe wire gage; 0.25 to 1.00 denote the sectional area as expressed in units of  $10^6$  circular mil =  $5.067$   $\text{cm}^2$ . Values of  $s$  correspond to integral numbers of feet (from 4 to 20); 1 ft. =  $30.5$  cm. Unit of size = B. & S. wire gage, or  $10^6$  cir. mil; of  $r$  and  $s = 1$  cm; of  $V_{ec} = 1$  kilovolt.

$s =$		122	152	183	245	305	366	426	490	610
Size	$2r$	$V_{ec}$ (stranded cables)								
4	0.584	56	58	60	62	64	66	68	69	71
3	0.663	62	65	67	70	72	74	76	77	80
2	0.736		71	73	76	79	81	83	85	87

TABLE 3.—(Continued)

$s =$		122	152	183	245	305	366	426	490	610
Size	$2r$	$V_{ec}$ (stranded cables)								
1	0.839		79	81	85	88	91	93	95	97
0	0.950			90	95	98	102	104	108	109
00	1.07			98	104	108	111	114	117	121
000	1.19				114	118	121	124	127	132
0000	1.35				125	130	135	138	141	146
0.25	1.50				138	144	149	152	156	161
0.30	1.57					151	156	161	165	171
0.35	1.73					161	166	170	175	180
0.40	1.85					171	176	180	185	192
0.45	1.96					178	184	190	194	200
0.50	2.04					188	194	199	205	210
0.80	2.62						234	241	244	256
1.00	2.92						256	264	270	281
Size	$2r$	$V_{ec}$ (wires)								
4	0.524	54*	56	58	60	62	64	65	66	68
3	0.581	59	62	64	66	68	70	72	74	76
2	0.655		69	70	74	76	78	80	82	84
1	0.734		75	77	81	83	86	88	90	92
0	0.826			85	89	92	95	97	99	102
00	0.928			94	98	102	105	107	110	113
000	1.04				109	113	116	119	121	124
0000	1.17					120	125	128	131	138

\* For  $s = 91$ ,  $V_{ec} = 51$ .

TABLE 4.—CORONA IN OIL

With coaxial cylindrical electrodes and alternating voltage,  $E_{mc}$  for pure, dry transil oil satisfies the following equation (21):

$$E_{mc} = 36(1 + c/\sqrt{r}) \text{ kilovolt/cm,}$$

where  $c^2 = 1.44$  cm. It changes only slightly with temperature between  $10$  and  $100^\circ\text{C}$ . Very slight traces of moisture (1 in 10 000) greatly reduce the sparkover and corona-forming voltages. Sparkover and corona are simultaneous if  $R < 300r$ .  $R$  = internal radius of outer cylinder.

### LITERATURE

(For a key to the periodicals see end of volume)

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## ELECTRICAL CONDUCTIVITY AND RESISTIVITY

COMPLETE INDEX Pure Substances	INDEX COMPLET Substances pures	GESAMT INDEX VERZEICHNIS Reine Stoffe	INDICE COMPLETO Corpi puri
Gases	Gas	Gase	Gas
All gases.	Tous les gaz.	Alle Gase.	Tutti gas. . . . . 110, 119, 156
Liquids	Liquides	Flüssigkeiten	Liquidi
Elements.	Éléments.	Elemente.	Elementi.
All elementary substances below $-80^{\circ}\text{C}$ .	Toutes les substances élémentaires au dessous de $-80^{\circ}\text{C}$ .	Alle elementaren Stoffe unterhalb $-80^{\circ}\text{C}$ .	Tutti gli elementi al di sotto di $-80^{\circ}\text{C}$ . . . . . 124
All metals above $-80^{\circ}\text{C}$ (except the rare earth metals).	Tous les métaux au dessus de $-80^{\circ}\text{C}$ (excepté les métaux des terres rares).	Alle Metalle oberhalb $-80^{\circ}\text{C}$ (ausgenommen die seltenen Erdmetalle).	Tutti i metalli sopra a $-80^{\circ}\text{C}$ (eccettuati i metalli delle terre rare). . . . . 135
S, Se and Te.	S, Se et Te.	S, Se und Te.	S, Se e Te. . . . . 141
All non-metallic elements and the rare earth metals above $-80^{\circ}\text{C}$ .	Tous les éléments non métalliques et les métaux des terres rares au dessus de $-80^{\circ}\text{C}$ .	Alle nichtmetallischen Elemente und die seltenen Erdmetalle über $-80^{\circ}\text{C}$ .	Tutti gli elementi non metallici e i metalli delle terre rare sopra $-80^{\circ}\text{C}$ . . . . . 142
Chemical Compounds.	Composés chimiques.	Chemische Verbindungen.	Composti chimici.
Salts.	Sels.	Salze.	Sali. . . . . 147
Water.	Eau.	Wasser.	Acqua. . . . . 152
All others.	Tous les autres.	Alle anderen Stoffe.	Tutti gli altri. . . . . 142
Solids	Solides	Feste Stoffe	Solidi
Elements.	Éléments.	Elemente.	Elementi.
All elementary substances below $-80^{\circ}\text{C}$ .	Toutes les substances élémentaires au dessous de $-80^{\circ}\text{C}$ .	Alle elementaren Stoffe unterhalb $-80^{\circ}\text{C}$ .	Tutti gli elementi sotto $-80^{\circ}\text{C}$ . . . . . 124
All metals above $-80^{\circ}\text{C}$ (except rare earth metals)	Tous les métaux au dessus de $-80^{\circ}\text{C}$ (excepté les métaux des terres rares).	Alle Metalle oberhalb $-80^{\circ}\text{C}$ (ausgenommen die seltenen Erdmetalle).	Tutti i metalli sopra $-80^{\circ}\text{C}$ (eccettuati i metalli delle terre rare). . . . . 135
S, Se and Te.	S, Se et Te.	S, Se und Te.	S, Se e Te. . . . . 141
All non-metallic elements and the rare earth metals.	Tous les éléments non métalliques et les métaux des terres rares.	Alle nichtmetallischen Elemente und die seltenen Erdmetalle.	Tutti gli elementi non metallici e i metalli delle terre rare. . . . . 153
Chemical Compounds.	Composés chimiques.	Chemische Verbindungen.	Composti chimici.
Salts in bulk.	Sels en masse.	Salze in homogener phase.	Sali in massa. . . . . 147
Ice.	Glace.	Eis.	Ghiaccio. . . . . 152
All others and all single crystals.	Tous les autres et tous les cristaux isolés.	Alle anderen Stoffe und einzel Kristalle.	Tutti gli altri composti e cristalli singoli. . . . . 153
Solutions and Mixtures	Solutions et mélanges	Lösungen und Mischungen	Soluzioni e miscugli
All gases.	Tous les gaz.	Alle Gase.	Tutti gas. . . . . 110, 119, 156
Liquids and Solids	Liquides et solides	Flüssigkeiten und feste Stoffe	Liquidi e solidi
Non-aqueous.	Non-aqueux.	Nichtwässrige Systeme. . .	Non acquosi.
Alloys, amalgams and commercial metals.	Alliages, amalgames et métaux du commerce.	Legierungen, Amalgame und Metalle des Handels.	Leghe, amalgame e metalli commerciali. . 156
Natural and industrial materials (see final index under class of material).	Matières naturelles et industrielles (voir l'index final sous classe des matières).	Natürliche und technische Materialien (siehe den Schluss-Index unter Natur der Materialien).	Materiali naturali e industriali (vedi l'indice in fondo sotto la categoria del materiale).
Salts and other mixtures above $150^{\circ}\text{C}$ .	Sels et autres mélanges au dessus de $150^{\circ}\text{C}$ .	Salze und andere Mischungen oberhalb $150^{\circ}\text{C}$ .	Sali ed altri miscugli sopra $150^{\circ}\text{C}$ . . . . . 153
Aqueous.	Aqueux.	Wässrige Systeme.	Acquosi. . . . . 229



PROPERTIES OF CARRIERS OF FREE ELECTRICITY IN GASES\*

LEONARD B. LOEB

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Introduction (general relations and explanation of terms).	Introduction (relations générales et explication des termes).	Einleitung (allgemeine Beziehungen und Erklärungen).	Introduzione (relazione generale e spiegazioni dei termini).....	110
Normal ions.	Ions normaux.	Normale Ionen.	Ioni normali.	
Mobility (old ions).	Mobilité (ions âgés).	Beweglichkeit (alte Ionen).	Mobilità (ioni vecchi).	
In air and pure gases.	Dans l'air et les gaz purs.	In Luft und reinen Gasen.	In aria e nei gas puri	111
In mixed gases.	Dans les mélanges gazeux.	In Gasmischungen.	Nei gas misti.....	112
Effect of pressure.	Effet de la pression.	Einfluss des Druckes.	Effetto della pressione	114
Effect of temperature.	Effet de la température.	Einfluss der Temperatur.	Effetto della temperatura.....	114
Mobility of newly formed ions.	Mobilité des ions nouvellement formés.	Beweglichkeit neugebildeter Ionen.	Mobilità di ioni formati da poco.....	114
Diffusivity.	Diffusibilité.	Diffusionsvermögen.	Diffusibilità.....	115
Coefficient of recombination.	Coefficient de recombinaison.	Wiedervereinigungskoeffizient.	Coefficiente di ricombinazione.	
At one temperature and pressure.	À une température et pression.	Bei einer Temperatur und einem Druck.	A una sola temperatura e pressione....	115
Effect of pressure.	Effet de la pression.	Einfluss des Druckes.	Effetto della pressione	115
Effect of temperature.	Effet de la température.	Einfluss der Temperatur.	Effetto della temperatura.....	115
Slow ions: mobility.	Ions lents: mobilité.	Langsame Ionen: Beweglichkeit.	Ioni lenti: mobilità.....	115
Electrons.	Électrons.	Elektronen.	Elettroni.	
Migrational and thermal velocities.	Vitesses de migration et thermiques.	Wanderungs- und thermische Geschwindigkeit.	Velocità di migrazione e termica.....	116
Number of impacts before attachment.	Nombre de chocs avant fixation.	Zahl der Zusammenstöße vor der Vereinigung.	Numero della collisioni prima della ricombinazione.....	116
Condensation of vapors on ions and nuclei.	Condensations des vapeurs sur les ions et les nuclei.	Kondensation von Dämpfen an Ionen und Kernen.	Condensazioni di vapore su ioni nuclei.....	117
Molecular areas effective in electron removal.	Surfaces moléculaires effectives dans le départ d'électron.	Molekularer Bereich für die Entfernung des Elektrons.	Aree molecolari efficaci nel rimuovere gli elettroni.....	117
* Covering data prior to March, 1928. For complete survey of the subject and complete bibliography, see (110).	* Contient les données antérieures à mars 1928. Pour avoir une vue d'ensemble complète du sujet et pour la bibliographie complète, voir (110).	* Daten soweit wie sie bis einschliesslich Februar 1928 bekannt geworden sind. Für die vollständige Übersicht dieses Gegenstandes und die gesamte Literatur, siehe (110).	* Comprende i dati anteriori al marzo 1928. Per una conoscenza completa del soggetto e per una bibliografia completa, vedi (110).	

INTRODUCTION

**Types of Ions.**—Three types of carriers may be distinguished: Normal ions, slow ions, and free electrons.

*Normal ions* are the carriers generally found in dry, dust-free gases at approximately atmospheric pressure. As far as is known (83, 97, 139), after the first few hundredths of a second they carry a single electronic charge ( $4.774 \times 10^{-10}$  es). Their mass is not known, but is of the same order as that of one to several molecules; their exact nature is an object of controversy (67, 81, 82, 96, 126) but it is certain that in some cases they consist of two or more molecules. Where the mobility of the completely formed positive ion is markedly less than that of the negative ion the mobility of the newly formed positive ion is abnormally great (33, 35, 36, 37, 38, 39, 41, 79, 136, 149, 152) and probably equals that of the negative ion (40, 87). In these gases the positive carrier seems to be completely formed after 0.03 second, and then its mobility no longer varies with its age. For gases in which the negative ion is the less mobile, no data exist. The mobility of both ions appears to be remarkably independent of the mass of the initially ionized molecule (10, 38, 40, 41, 42, 49, 61, 67, 82, 100, 125, 153). In at least one case (40) this can be ascribed to a transfer of the charge from an ionized molecule of higher ionizing potential to one of a lower; in other cases, such as with radioactive ions (36, 39, 42),

this is not so. The nature of the completely formed ion does not depend upon the process by which it was formed (38, 39, 41, 42, 49, 73) provided this process does not directly give rise to charged particles of more than molecular mass. It does however very much depend on the electrical and chemical nature of the surrounding gases with which it has had time to come into equilibrium (41, 81, 82, 96). In gases with a negative mobility higher than that of the positive; the mobility of the negative ion is independent of its age; abnormalities observed at low pressures are attributed to a delay in the attachment of the electrons to neutral molecules to form negative ions (50, 55, 56, 68, 69, 77, 97, 134, 155, 156); in some gases, an electron must make many collisions with molecules before attaching to one to form an ion (see Table 12). In certain pure gases [He, A (43), N<sub>2</sub>, H<sub>2</sub> (68), CO (150) and probably NH<sub>3</sub>] the electron cannot attach itself to a molecule to form an ion. In such cases the negative ions are formed by the attaching of the electrons to impurities which may be present; these negative ions have mobilities which are of the same order of magnitude as those of positive ions.

*Slow ions* consist of pre-existing nuclei, of more than molecular mass, to which normal ions have become attached (45, 112). Their mobilities appear to vary somewhat with age (8, 9, 18, 19, 20, 21, 22, 23, 45). Two definite types (107, 108, 112) of such



ions have been found in moist air. Type I is characterized by a mobility which decreases as the partial pressure of the water vapor is increased; these are not found when the partial pressure exceeds 17 mm of mercury (108). Type II (62, 63, 107), the so-called Langevin ion, is found at all humidities; and its mobility depends, not upon the partial pressure, but upon the relative humidity, decreasing as the latter increases (8, 9, 18, 19, 20, 21, 22, 23, 90, 98, 99, 101, 102, 103, 145). Besides the ions included in these two types, there are other carriers formed by the attachment of normal ions to solid particles of various sizes; the mobilities of these vary with the size of the particles; these will be called *heterogeneous slow ions*.

**Electrons.**—The velocity ( $v$ ) of migration of free electrons is not proportional to the intensity of the electric field causing the migration (4, 70, 71, 112, 139, 143, 144). Under the action of an impressed electric field, the velocity of thermal agitation of the electrons exceeds (139, 143, 144) that of the surrounding gas molecules by a factor ( $c$ ) depending upon both the field strength ( $F$ ) and the pressure ( $P$ ) of the gas. Within the limits covered by observations, the values of  $c$  and of  $v$  at a specified temperature and for a given gas are quite closely determined by the ratio  $F/P$ . See Table 11. (For theoretical discussions, see (25, 26, 51)).

**Coefficient of Recombination of Ions.**—Our knowledge of the coefficient of recombination of ions in gases is in a highly unsatisfactory state. Beside difficulties due to columnar ionization in the case of ionization by  $\alpha$ -particles (131), no matter what the source of ionization, the initial density and distribution of ions are not known, and erroneous assumptions in this regard may lead to values of the coefficient ( $\alpha$ ) which are seriously in error. Thus, Rümelin (120) and Plimpton (106) have found that, during a short interval immediately following the formation of the ions,  $\alpha$  has an apparent value that is five times the corresponding value reported below (Tables 7, 8, 9). This may be due in part to an initial recombination of free electrons with  $+$  ions (84). Values obtained by the use of  $\alpha$ -particles have been eliminated as far as possible from Tables 7, 8, and 9, later values obtained in other ways being given. Most observers find that at low pressures and room temperatures  $\alpha$  increases nearly proportionally to  $P$ , but at pressures greater than 1 atm. it approaches a constant value. Data for variation with temperature are discordant; those of Erikson are probably the best, and indicate that  $\alpha$  increases with the temperature.

**Mobility ( $k$ ).**—The mobility of an ion = velocity of migration per unit electrical field intensity. Over a wide range of densities ( $d$ ),  $kd$  is a constant for a given gas. (See Table 4.) Value of  $k$  at 0°C and 760 mm of mercury at 0°C, is often called the mobility constant =  $k_0$ . Uncertainties in the proper interpretation of the observations and slight variations in the experimental procedure (73, 74, 128, 146), as well as traces of unsuspected active impurities present in any one of a series of gases, may introduce variations of 20 to 30% in the inferred value of  $k$ ; but relative values obtained under comparable conditions (41, 81, 96, 112, 139, 147) are quite accurate except for the selective action of impurities. For methods of measurement and interpretation of observations, see (24, 33, 45, 46, 49, 56, 57, 60, 73, 74, 112, 118, 128, 160). For attempts at establishing theoretical relations between  $k$  and other properties of the gas, see (45, 61, 67, 76, 82, 94, 112).

**Effective Sectional Area of Molecule.**—See p. 117.

TABLE 1.—MOBILITY CONSTANT OF NORMAL IONS IN GASES

For mixed gases other than air, see Table 2

Except as another is indicated, pressure = 760 mm of Hg, temperature = 15°C. Methods:  $B$  = air-blast,  $C$  = current measurement,  $F$  = Franck's,  $L$  = Langevin's,  $R$  = Rutherford's,  $T$  = Tyndall and Grindley's;  $F$ ,  $R$ , and  $T$  are alternating current methods. Range in value is indicated by {;  $el$  = negative carriers

are free electrons;  $i$  = gas was slightly impure;  $p$  = gas was pure, giving free electrons even at high pressures. Mobility constant is  $k_0 = kd/d_0$  where  $d_0$  = density at 0°C and 760 mm of Hg and  $d$  = density when  $k$  was measured; excepting at the higher temperatures the values of  $k$  given below do not differ significantly from  $k_0$ . Data marked \* have been reduced by dividing the observed values by 1.21 so as to bring them to the same basis as the others which were obtained by methods yielding a doubtful low value (see (73, 74, 128, 146)); it is believed that  $k = 1.21M$  in all cases; subscripts ( $+$ ,  $-$ ) indicate the ion to which  $M$  refers. Unit of  $k = 1 \text{ cm sec}^{-1}$  per volt  $\text{cm}^{-1} = 1 \text{ cm}^2 \text{ volt}^{-1} \text{ sec}^{-1}$ .

Gas	$M_+$	$M_-$	Method	Lit.
Air.....	1.36 1.37 1.40 1.36* 1.57*	1.87 1.80 1.70 1.70* 1.82* 2.02*	$B$ $F$ $L$ $R$ $F, p$ $F, R$ $T$	(160) (46) (60) (56) (128) (73) (146)
A.....	1.37 1.37	1.70 $el$	$F, i$ $F, p$	(43) (43)
$\text{Cl}_2$ .....		0.73	$F$	(148)
$\text{H}_2$ .....	6.70 5.33† 6.02 5.52 5.34* 5.11 4.96*	7.95 $el$ 7.68 8.71 8.22* 9.67 8.35*	$B, i$ $F, p$ $F, i$ $F, i$ $F, i$ $F, i$ $F, i$	(160) (88) (46) (158) (88) (156) (96)
He.....	5.09 5.09	6.31 $el$	$F, i$ $F, p$	(46) (45)
$\text{N}_2$ .....	1.27 1.27 1.32	1.84 $el$ 1.79	$F, i$ $F, p$ $F, i$	(44) (44) (158)
$\text{O}_2$ .....	1.36 1.29	1.80 1.79	$B$ $F$	(160) (43)
$\text{CO}$ .....		0.99*	$R, p$	(148)
$\text{CO}_2$ .....	1.10 0.76 0.86 0.83 0.73 0.76 0.30	1.14 1.02* 0.81 0.90 1.02 0.99 0.31	$L$ $R, p$ $B$ $L$ $F, p$ $F$ $L$	(154) (72) (160) (60) (112†) (156) (112†) (154)
$\text{CCl}_4$ .....	0.30	0.95	$B, 100^\circ$	(110)
$\text{H}_2\text{O}$ .....	1.1 0.77 0.62	0.73 0.56	$B$ $F$	(109) (86)
$\text{HCl}$ .....	1.27† 0.65*	0.56* 0.56*	$C$ $F$	(123) (80)
$\text{NH}_3$ .....	0.74 0.62*	0.80 0.67*	$L$ $F$	(154) (81)
$\text{N}_2\text{O}$ .....	0.82	0.64* 0.90 1.10*	$R, p$ $L$ $R$	(148) (154) (72)
$\text{SO}_2$ .....	0.415 0.412	0.414 0.414	$F$ $F$	(155) (159)
$\text{H}_2\text{S}$ .....	0.59	0.57	$F$	(88)

Gas	Formula	$M_+$	$M_-$	Method	Lit.
Acetylene.....	$\text{C}_2\text{H}_2$	0.71*	0.95* 0.77*	$R, p$ $F, p$	(148) (87)
Benzene.....	$\text{C}_6\text{H}_6$	0.18	0.21	$B$	(109)
Ethane.....	$\text{C}_2\text{H}_6$		1.07*	$R$	(148)
Ethylene.....	$\text{C}_2\text{H}_4$		0.75*	$R$	(148)



TABLE 1.—(Continued)

Gas	Formula	$M_+$	$M_-$	Method	Lit.
n-Hexane.....	$C_6H_{14}$	0.15	0.16	B	(109)
n-Pentane.....	$C_5H_{12}$	0.36	0.35	L	(154)
		0.385	0.451	F	(159)
Chloroform.....	$CHCl_3$	0.19	0.16	B	(109)
Ethyl chloride.....	$C_2H_5Cl$	0.304	0.317	F	(159)
		0.33	0.31	L	(154)
Ethyl iodide.....	$C_2H_5I$	0.17	0.16	L	(154)
		0.181	0.181	F	(159)
Methyl bromide.....	$CH_3Br$	0.29	0.28	L	(154)
Methyl iodide.....	$CH_3I$	0.24	0.233	F	(155)
		0.216	0.226	F	(159)
Isobutyl alcohol.....	$C_4H_{10}O$	0.21	0.21	B, 105°	(110)
Ethyl alcohol.....	$C_2H_6O$	0.39	0.412	F	(155)
		0.363	0.373	F	(159)
Isoamyl alcohol.....	$C_5H_{12}O$	0.19	0.23	B, 130°	(110)
Methyl alcohol.....	$CH_4O$	0.37	0.38	B, 66°	(110)
		0.29	0.30	B	(109)
n-Propyl alcohol.....	$C_3H_8O$	0.22	0.22	B, 97°	(110)
Acetaldehyde.....	$C_2H_4O$	0.31	0.30	L	(154)
		0.307	0.331	F	(159)
Acetone.....	$C_3H_6O$	0.31	0.29	L	(154)
		0.236	0.247	F	(159)
Ethyl acetate.....	$C_4H_8O_2$	0.31	0.28	L	(154)
		0.16	0.19	B, 77°	(110)
		0.226	0.247	F	(159)
		0.19	0.24	B, 58°	(110)
Methyl acetate.....	$C_3H_6O_2$	0.33	0.36	L	(154)
n-Propyl acetate.....	$C_5H_{10}O_2$	0.15	0.17	B, 100°	(110)
Ethyl formate.....	$C_3H_6O_2$	0.30	0.31	L	(154)
Ethyl ether.....	$C_4H_{10}O$	0.29	0.31	L	(154)
		0.19	0.22	F	(79)
		0.15	0.16	B	(109)

\* Observer's value is  $k = 1.21M$ . † Page 324. ‡ Sum of + and - mobilities.

TABLE 2.—MOBILITY ( $k$ ) OF NORMAL IONS IN MIXED GASES

If  $p_a$  and  $p_b$  = the partial pressures of the constituents A and B of a binary mixture,  $P = p_a + p_b$ ,  $c_a = 100p_a/P$ , and  $c_b = 100p_b/P$ , then  $c_a$  and  $c_b$  are the per cent concentrations of the two constituents. If  $k_a$ ,  $k_b$ ,  $k_{ab}$  are the mobilities for the pure gases and for the mixture, all reduced to 760 mm of Hg, then  $k_{ab} = 100k_a k_b / (c_a k_b + c_b k_a)$  in the following cases: Both ions in  $CO_2 + H_2$ , and  $CO_2 +$  air (Blanc (10)), in  $C_2H_2 + H_2$  (Loeb (87)), and in  $O_2 + H_2$  (Mayer (96)); for + ions in  $CH_3I + H_2$  (Wellisch (153)); and for - ions in  $(C_2H_5)_2O + H_2$  (Loeb (81)). For both ions in  $NH_3 +$  air (Loeb (85)) and for + ions in  $Cl_2 + H_2$  (Mayer (96)),  $k_{ab} = k_a k_b / \sqrt{(c_a k_b^2 + c_b k_a^2) / 100}$  fits the observations better. For all other mixtures yet studied, the data depart markedly from these laws if the concentration of the gas of lower mobility is small, but approximate one or other of them as this concentration is increased; see also (7, 81, 147).  $c_v$  = percentage of vapor. Unit of  $k = 1 \text{ cm}^2/(\text{volt sec})$ ; of  $c = 1\%$ ; of  $P = 1 \text{ mm of Hg}$ .

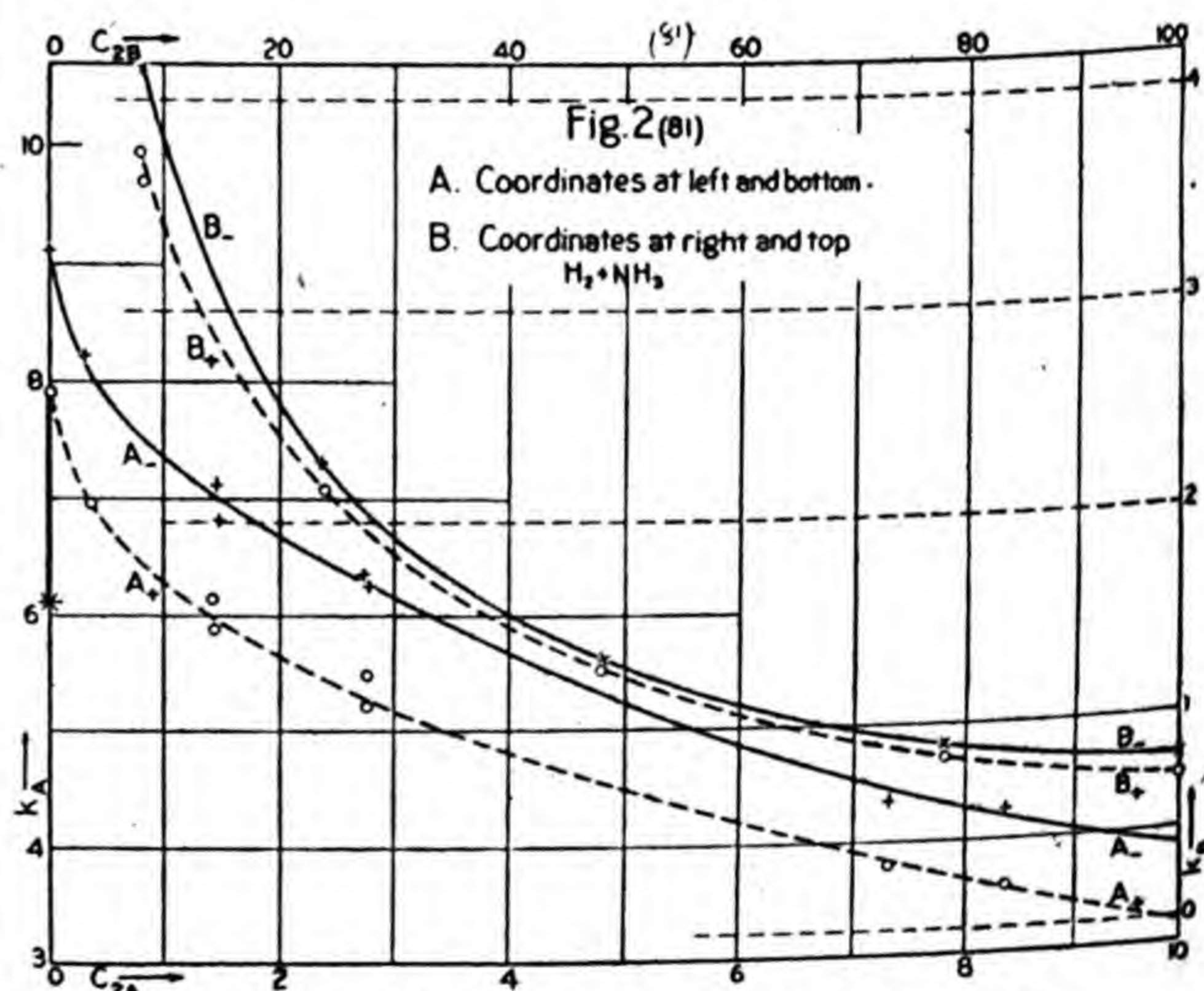
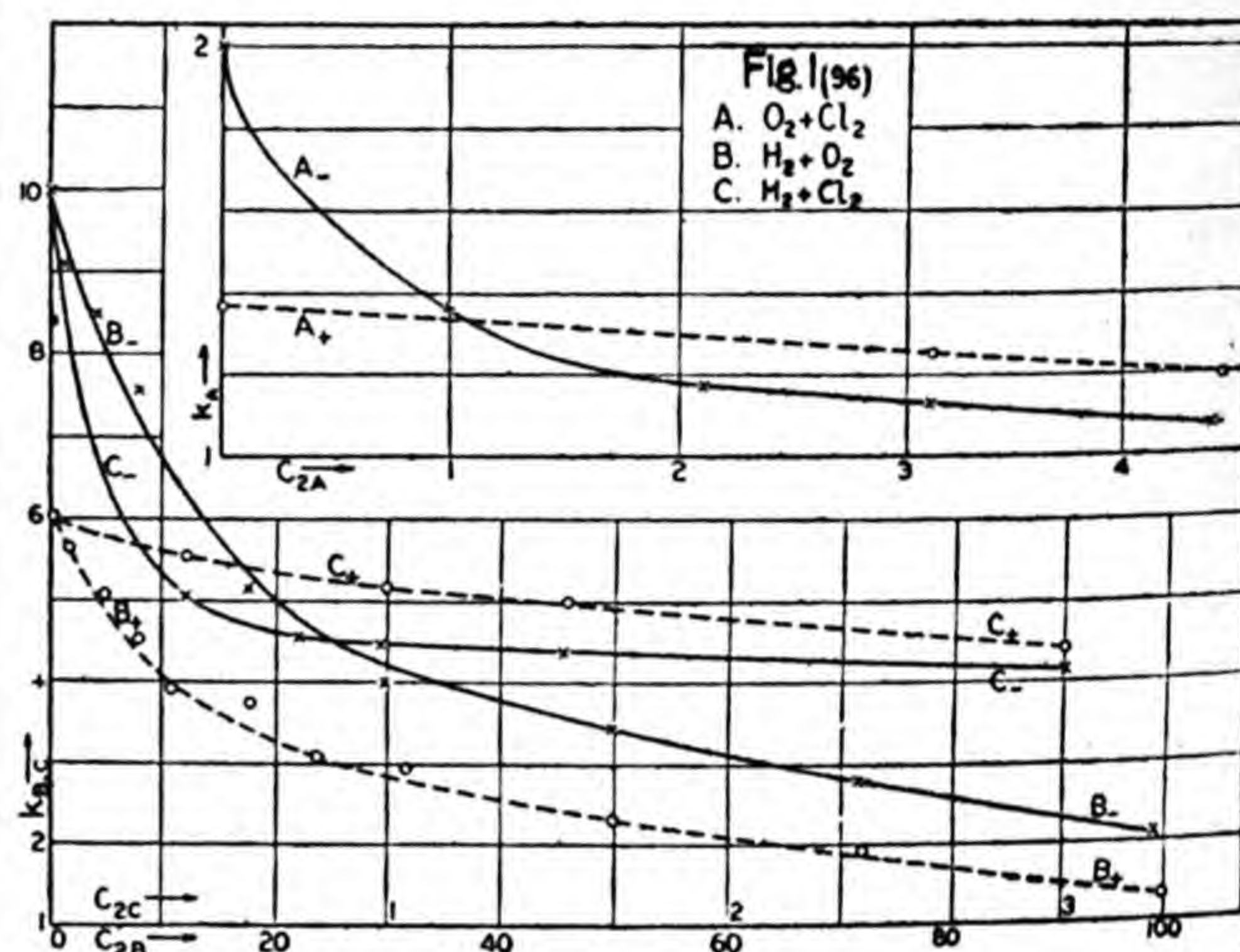
Air + vapor (see also Fig. Index)

Vapor	$c_v$	$k_+$	$k_-$	$P$	$t, ^\circ C$	Lit.
None.....	0	1.37	1.80	737	15	(153)
$H_2O^*$ .....	0.0	1.38	2.11	566	25	(96)
	1.6	1.38	2.00	539	25	(96)
	2.4	1.35	1.85	535	26.5	(96)
	2.5	1.32	1.83	535	23	(96)
	3.0	1.25	1.63	522	23	(96)
$CH_3I$ .....	0.81	1.37	1.80	737	15	(153)
$C_2H_5Br$ .....	0.81	1.32	1.80	737	15	(153)
$C_2H_5OH$ .....	1.32	0.91	1.10	755	15	(153)
$C_2H_6O$ .....	1.19	1.15	1.37	755	15	(153)

\* For  $H_2O$ ,  $k$  has been reduced to basis of  $P = 760 \text{ mm}$ .

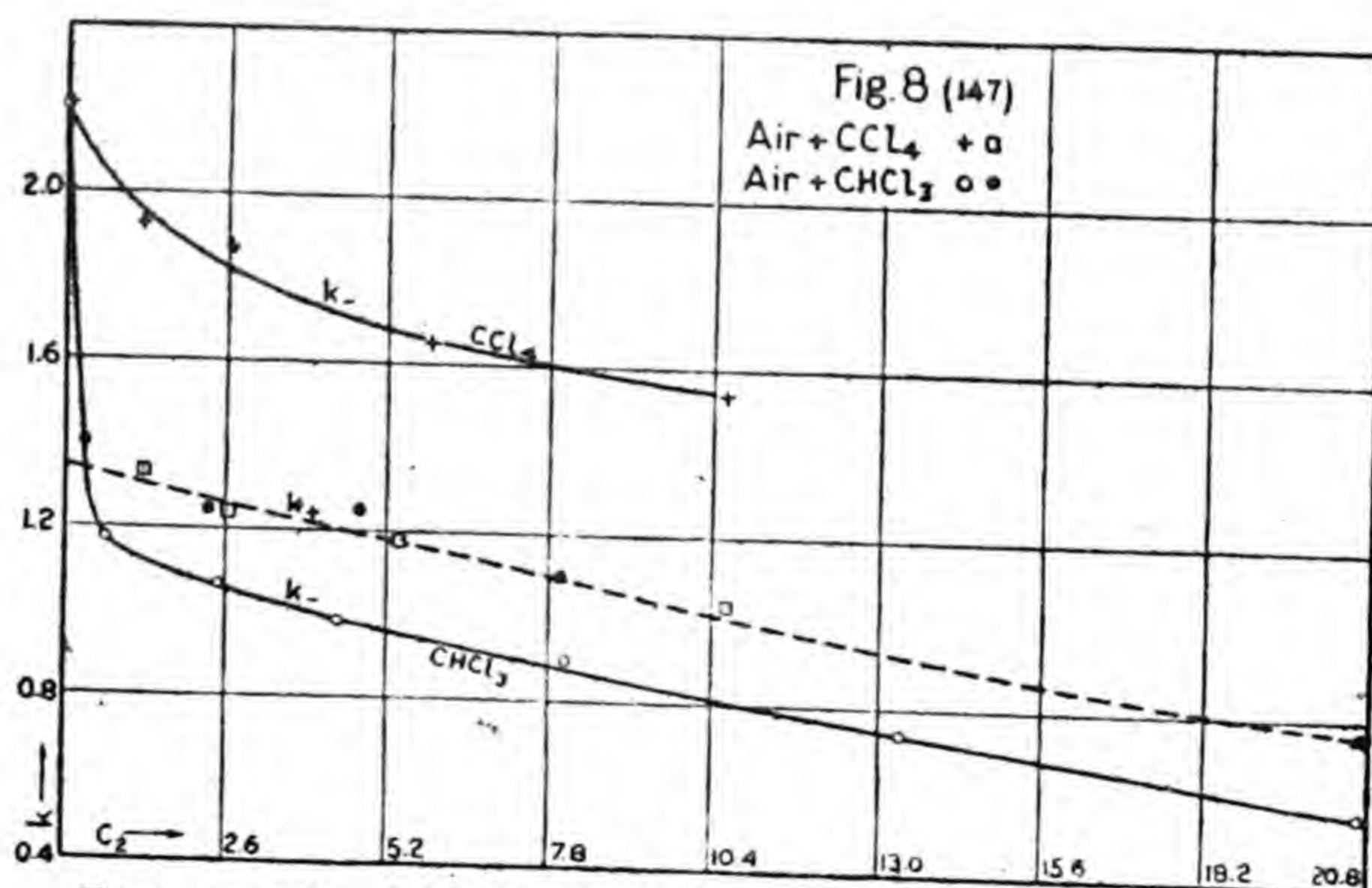
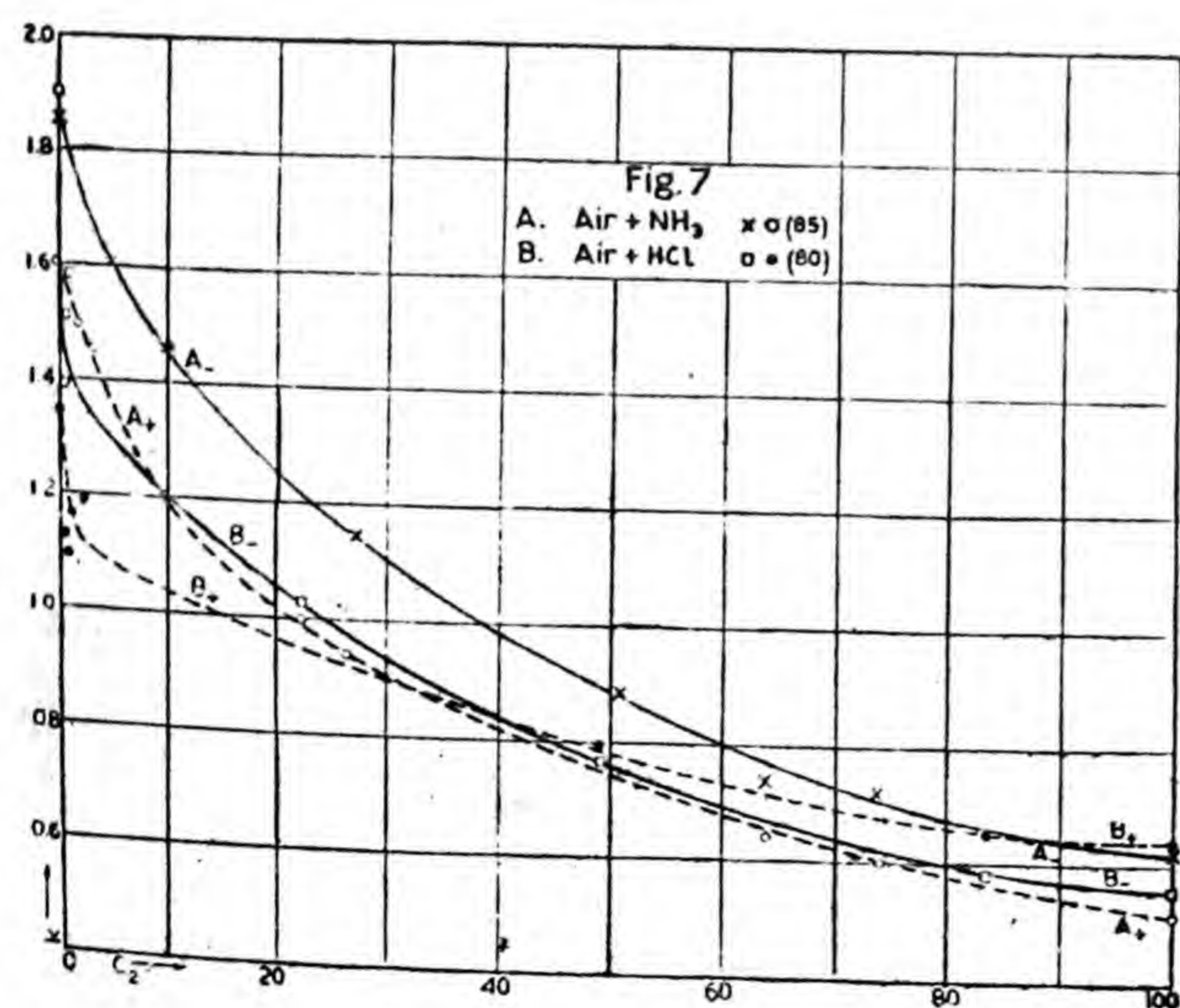
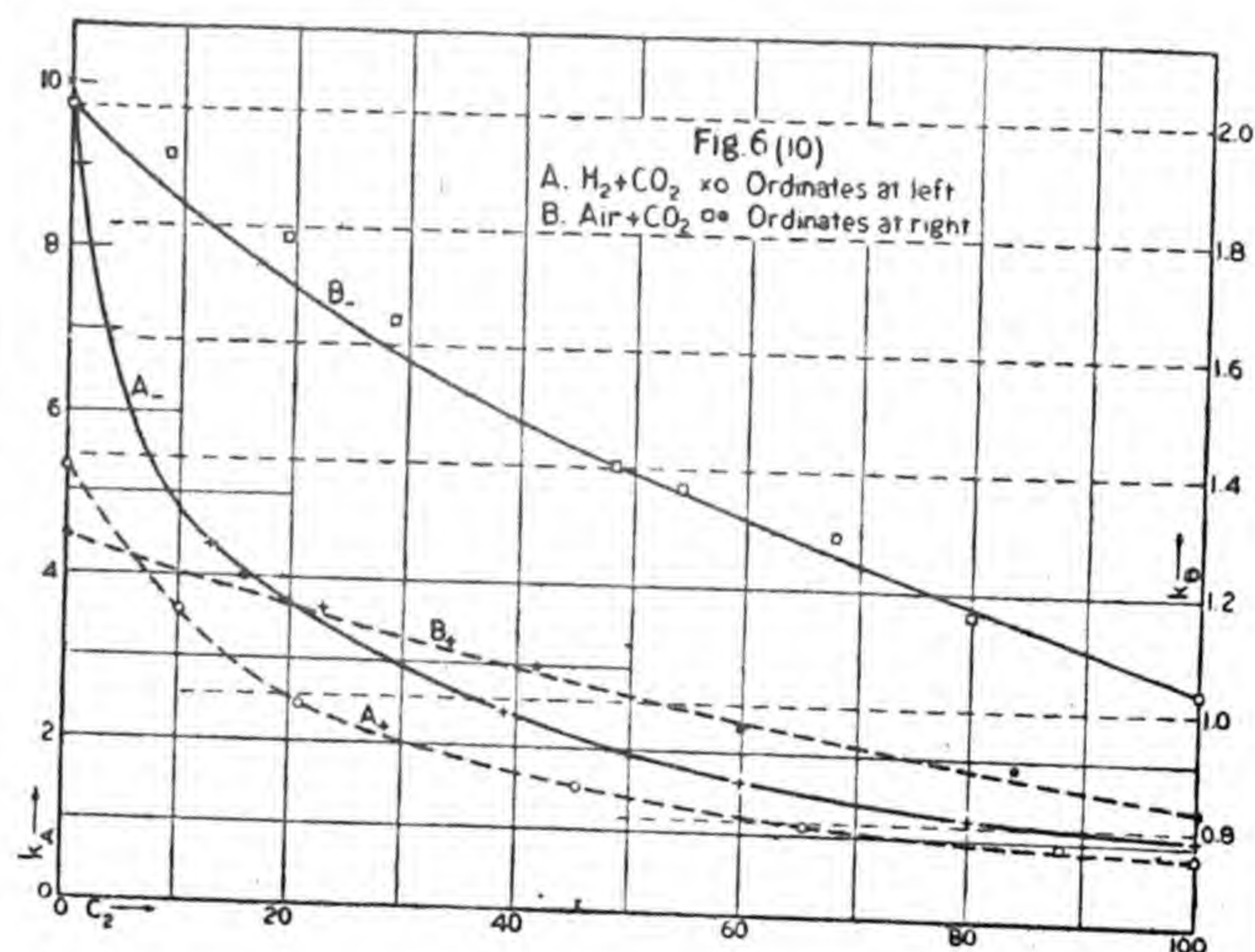
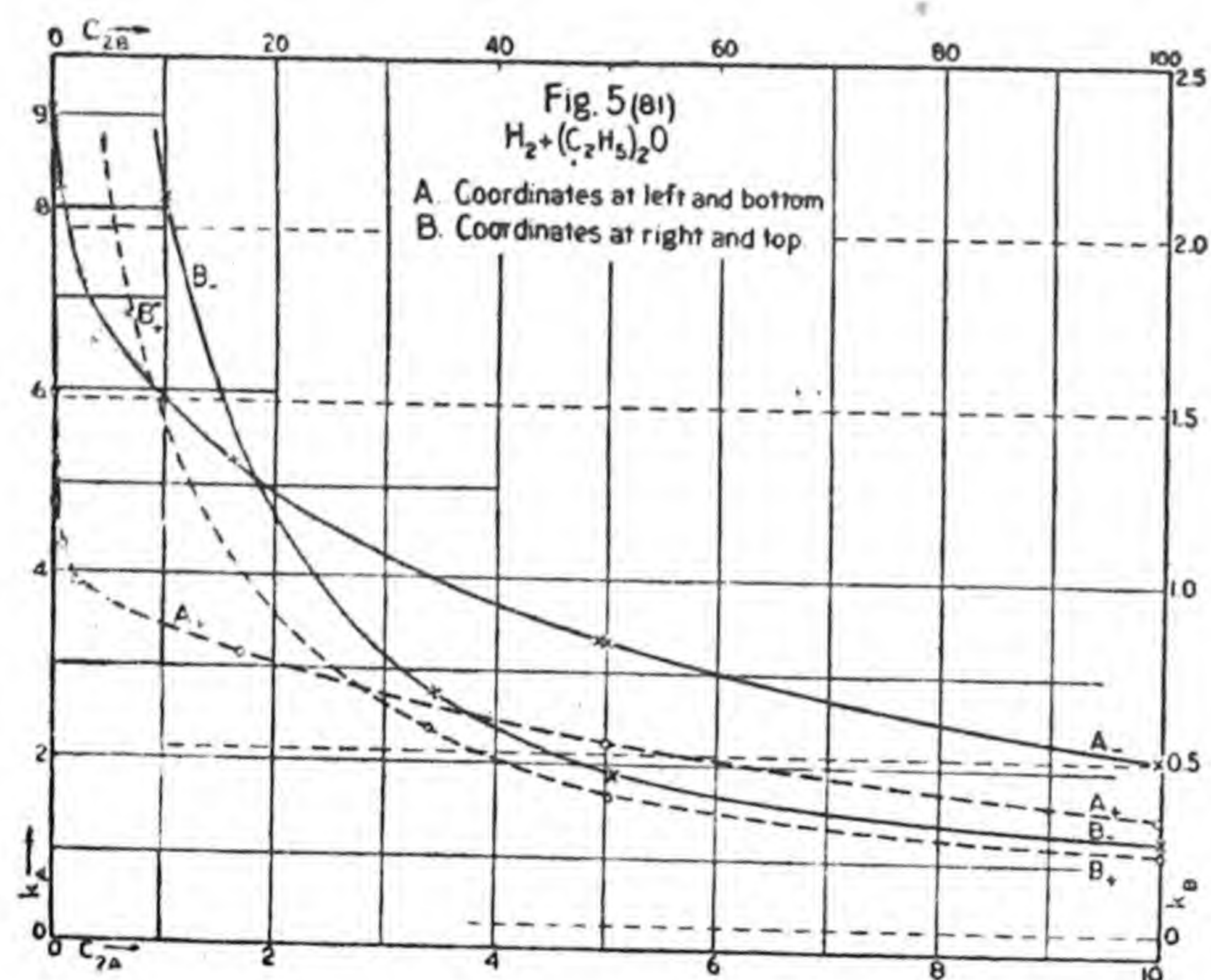
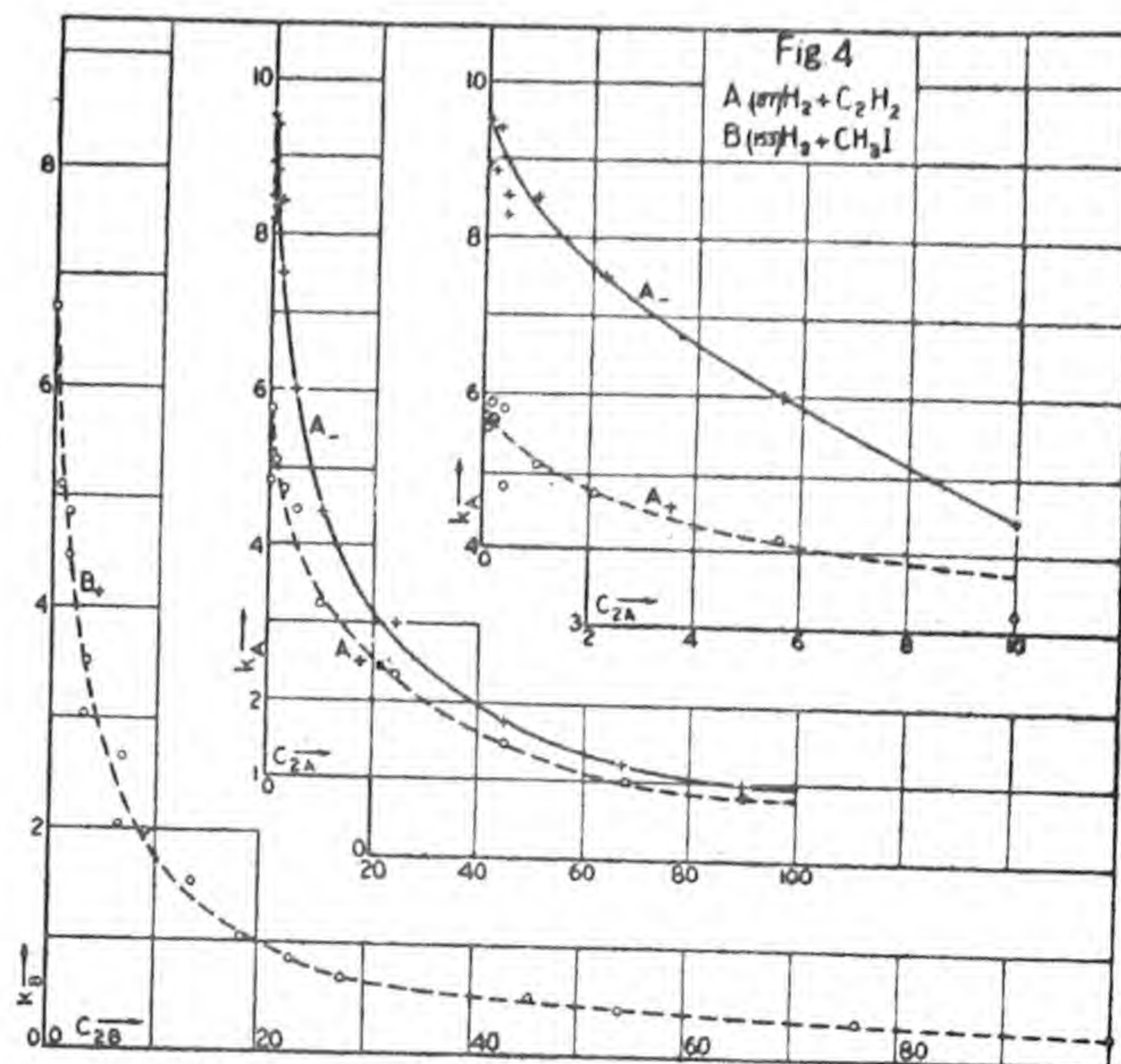
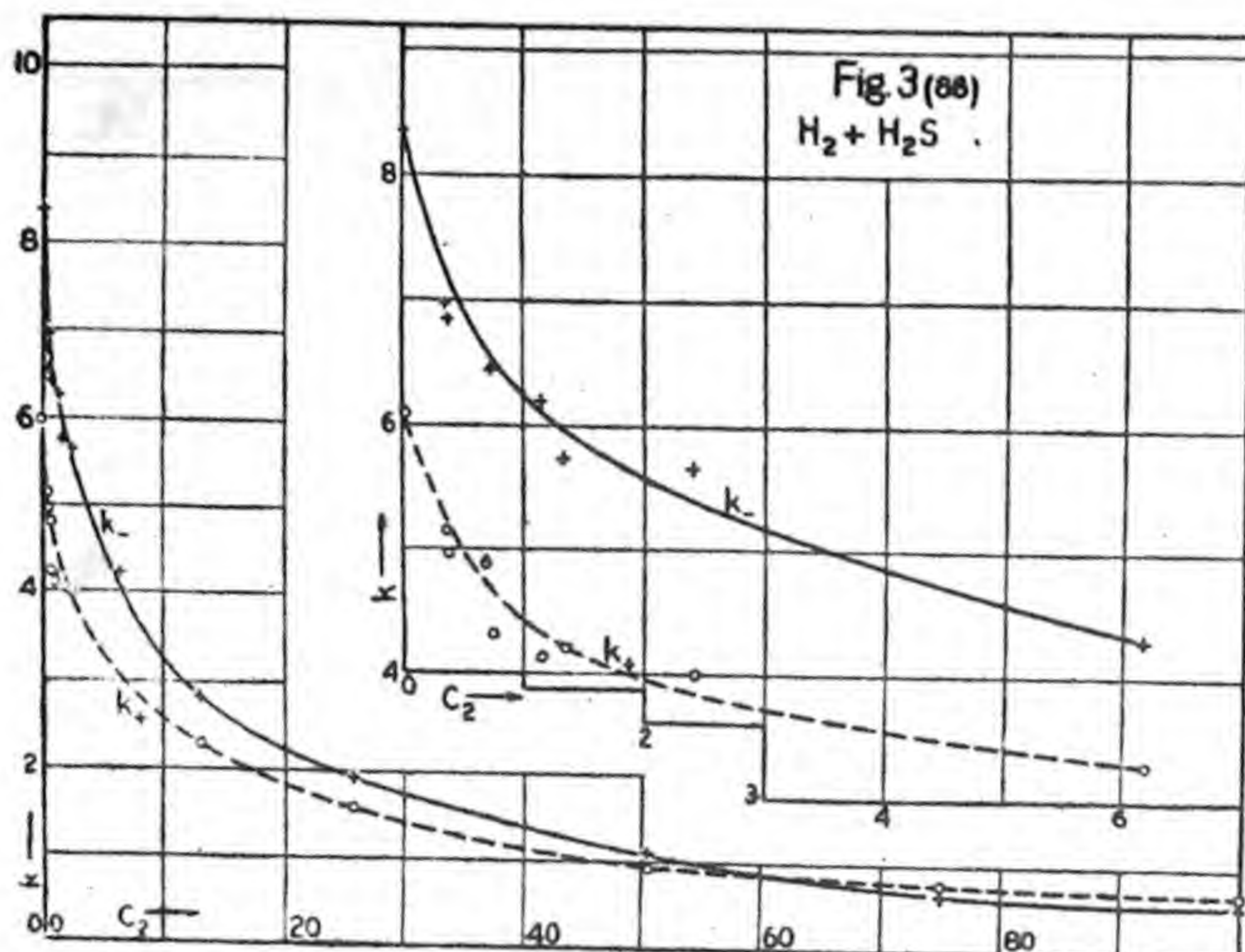
Figure Index

Mixture	Fig.	Mixture	Fig.
Air + $H_2O$ .....	9	Air + $n-C_5H_{11}OH$ .....	9
Air + $HCl$ .....	7	$O_2 + H_2$ .....	1
Air + $NH_3$ .....	7	$O_2 + Cl_2$ .....	1
Air + $CO_2$ .....	6	$H_2 + Cl_2$ .....	1
Air + $CCl_4$ .....	8	$H_2 + H_2S$ .....	3
Air + $CHCl_3$ .....	8	$H_2 + NH_3$ .....	2
Air + $CH_3OH$ .....	9	$H_2 + CO_2$ .....	6
Air + $C_2H_5OH$ .....	9	$H_2 + (C_2H_5)_2O$ .....	5
Air + $n-C_3H_7OH$ .....	9	$H_2 + CH_3I$ .....	4
Air + $n-C_4H_9OH$ .....	9	$H_2 + C_2H_2$ .....	4



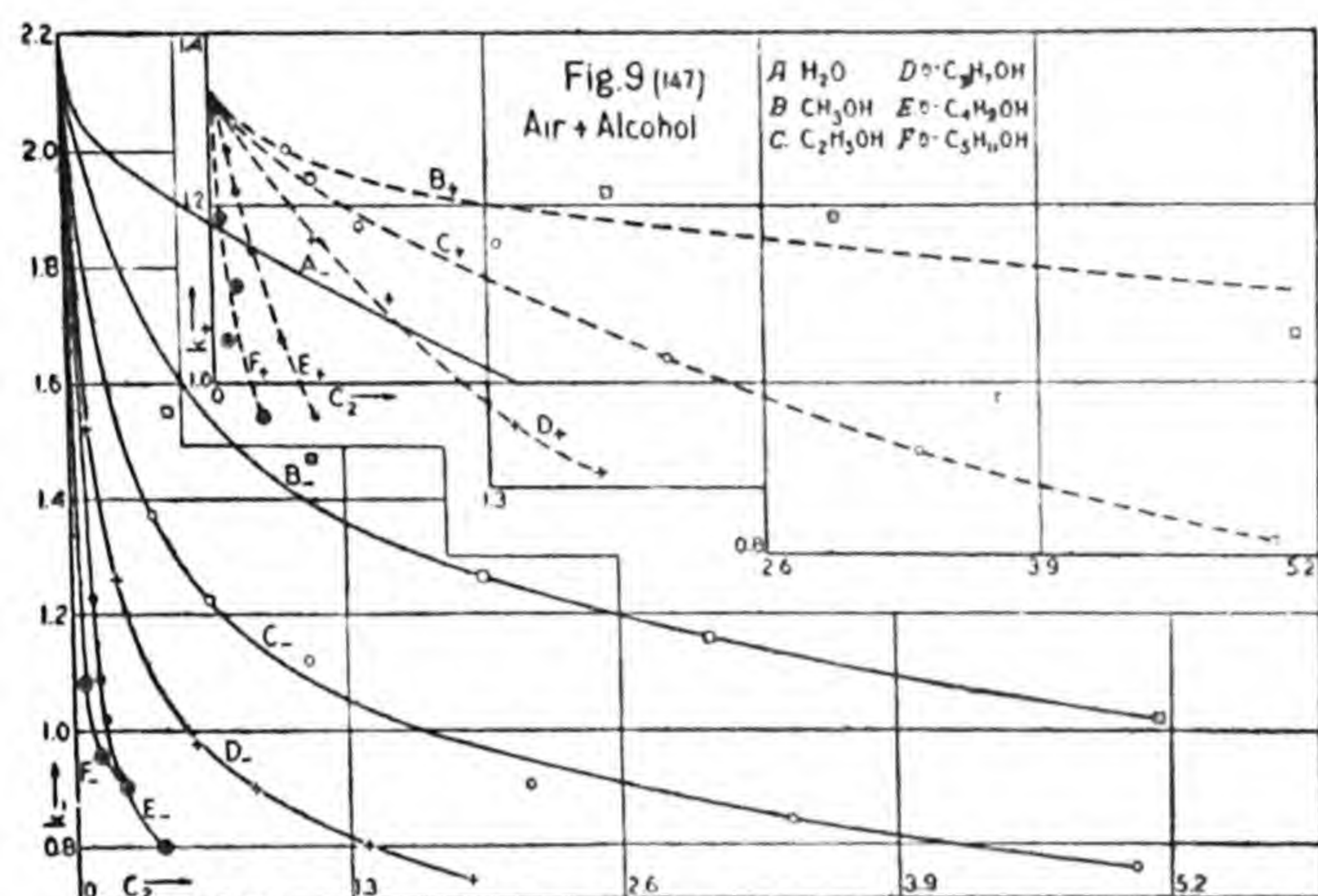
FIGS. 1 TO 9.—Mobility ( $k$ ) of normal ions in mixed gases. (For symbols and index, see Table 2.)  $P = 760 \text{ mm Hg}$ ,  $t = 15^\circ C$ ,  $C_1$  = concentration of the second constituent; e.g. in Fig. 2,  $C_1$  = concentration of  $NH_3$ ; sign of ion is indicated by a subscript, + or -; literature reference is enclosed in ( ). Unit of  $C_1 = 1\%$ ; of  $k$  is nominally  $1 \text{ cm}^2/(\text{volt sec})$  but data are suitable for ratios only within the group of which they form a part.





FIGS. 1 to 9.—Mobility ( $k$ ) of normal ions in mixed gases. (For symbols and index, see Table 2.)  $P = 760$  mm Hg,  $t = 15^\circ\text{C}$ ,  $C_1 =$  concentration of the second constituent; e.g. in Fig. 2,  $C_2 =$  concentration of  $\text{NH}_3$ ; sign of ion is indicated by a subscript, + or -; literature reference is enclosed in ( ). Unit of  $C_2 = 1\%$ ; of  $k$  is nominally  $1 \text{ cm}^2/(\text{volt sec})$ , but data are suitable for ratios only within the group of which they form a part.



FIGS. 1 to 9.—Mobility ( $k$ ) of normal ions in mixed gases.

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TABLE 3.—MOBILITY ( $k$ ) OF NORMAL IONS: VARIATION WITH PRESSURE ( $P$ )

For a given gas at a given temperature,  $Pk$  is a constant if  $P$  lies between a few mm of Hg and 75 or 100 atm. (27, 57, 59, 92, 136, 149, 156); at other pressures, variations are observed. At least a part of the variation at low pressures arises from the fact that an appreciable fraction of the ions present are not completely formed (56, 97, 155, 156) (cf. Table 5). Sign of ion is indicated by subscript + or -. Recent results in  $\text{SO}_2$  indicate that for saturated vapors this law may not hold (89). Unit of  $k = 1 \text{ cm}^2/(\text{volt sec})$ ; of  $P = 1$  mm of Hg or 1 atm. Temperature =  $15^\circ\text{C}$ .

$P$	$Pk_+$	$Pk_-$	$P$	$Pk_+$	$Pk_-$	$P$	$Pk_+$	$Pk_-$
Air (57) $P$ , atm.			Air (92).—(Cont'd)			$\text{CO}_2^*$ .—(Cont'd)		
13.3	1.32	1.84	155.04	1.68	2.21	0.93	1.30	
21.1	1.30	1.75	164.73	1.71	2.32	0.525	1.40	
31.2	1.35	1.87	175.40	1.61	2.19	0.507	1.50	
36.8	1.37	1.87	181.50	1.65	2.17	0.451	1.55	
41.7	1.32	1.87	$\text{O}_2^*$ (136) $P$ , mm			0.350	1.65	
47.6	1.30	1.86	1.57	1.59		0.300	1.78	
50.6	1.32	1.85	1.39	1.86		0.210	1.70	
53.0	1.37	1.94	1.27	1.78		0.136	1.72	
59.5	1.34	1.89	1.06	1.99		0.091	2.22	
70.6	1.36	1.91	0.79	2.08		0.053	2.27	
74.6	1.39	1.96	0.63	2.09		$\text{H}_2^*$ (136) $P$ , mm		
Air (92) $P$ , atm.			0.48	2.48		3.54	6.32	
66.86	1.32	1.89	0.41	2.71		2.68	6.64	
87.21	1.41	1.86	0.25	2.60		1.50	6.40	
96.90	1.46	1.89	0.172	3.63		1.27	7.36	
108.50	1.48	2.04	0.151	2.96		0.99	8.00	
116.28	1.50	2.07	0.091	3.55		0.67	8.42	
123.10	1.52	2.05	$\text{CO}_2^*$ (136) $P$ , mm			0.42	8.95	
132.75	1.60	2.04	1.47	1.09		0.38	9.60	
145.35	1.60	2.21	1.13	1.20				

\* Thermions from hot salts.

TABLE 4.—MOBILITY ( $k$ ) OF NORMAL IONS IN DRY AIR: VARIATIONS WITH TEMPERATURE ( $T$ )

At constant density and near room temperature,  $k$  is practically independent of  $T$ . For theoretical and other discussions, see (45, 61, 76, 112, 128).  $P =$  pressure; sign of ion is indicated by subscript + or -. Unit of  $k = 1 \text{ cm}^2/(\text{volt sec})$ .  $T =$  absolute temperature,  $^\circ\text{K}$ ;  $T_0 =$  value of  $T$  at  $0^\circ\text{C}$ .

TABLE 4.—(Continued)

$T$ , $^\circ\text{K}$	$(kT_0/T)_-$	$T$ , $^\circ\text{K}$	$(kT_0/T)_+$	$(kT_0/T)_-$	$T$ , $^\circ\text{K}$	$k_{+ \dagger}$	$k_{- \dagger}$
$P = 1$ atm. (56)		$P = 1$ atm. (104)		Constant density* (32).—(Cont'd)			
698	2.19	411	1.33	1.66	311	1.209	1.81
648	2.32	399	1.34	1.64	297	1.327	1.740
570	2.15	383	1.32	1.64	273	1.365	1.755
540	2.20	373	1.33	1.62	252	1.30	1.663
503	2.18	348	1.31	1.67	Constant density (31)		
468	2.30	333	1.31	1.64	$T$ , $^\circ\text{K}$	$k_+$	$k_-$
463	2.20	285	1.33	1.71	293	1.35	1.89
428	2.35	209	1.24	1.61	209	1.34	1.82
416	2.27	94	0.682	0.68	93	1.20	1.24
409	2.22	Constant density* (32)			Constant density† (128)		
388	2.05	$T$ , $^\circ\text{K}$	$k_{+ \dagger}$	$k_{- \dagger}$	$T$ , $^\circ\text{K}$	$k_{+ \parallel}$	$k_{- \parallel}$
378	2.00	336	1.207	1.729	288	1.88	2.43
360	2.00	335	1.278	1.809	332	1.86	2.47
340	2.10	306	1.326	1.777	395	1.75	2.33
335	2.04	297	1.364	1.693	$T$ , $^\circ\text{K}$	$k_{+ \P}$	$k_{- \P}$
300	1.91	273	1.361	1.522	288	1.59	2.21
296	1.88	252	1.321	1.596	370	1.52	2.43
268	1.83	89	1.20	1.24	288	1.62	2.29
237	1.77	$T$ , $^\circ\text{K}$	$k_{+ \dagger}$	$k_{- \dagger}$			
202	1.53	343	1.101	1.510			
180	1.32	325	1.178	1.701			
149	1.14						
84.5	0.717						

\* The density is that corresponding to  $0^\circ\text{C}$  and 1 atm.† Air dried over  $\text{CaCl}_2$  and liquid air; vessel unheated.‡ Air dried over liquid air; during filling, vessel heated to  $373^\circ\text{K} = 100^\circ\text{C}$ .§ The density is that corresponding to  $15^\circ\text{C}$  and 1 atm.

|| Air of highest purity in contact with Na.

¶ Dry air of less purity.

TABLE 5.—MOBILITY ( $k$ ) OF NEWLY FORMED IONS

Very new + ions have the same mobility as the - ions; mobility of - ions appears to be independent of age. Values of  $k$  on any one line of the table are relatively correct, but are not in all cases comparable with those on any other line.

$U_n =$  upper limit for the age of the new ions;  $L_o =$  lower limit for the old ions. The same age limits apply to both + ions and - ions. Pressure = 760 mm of mercury; temperature =  $15^\circ\text{C}$ . Unit of  $U$  and  $L = 1$  sec; of  $k = 1 \text{ cm}^2/(\text{volt sec})$ .

Gas	Carrier	Age limits		$k_+$		$k_-$		Lit.
		$U_n$	$L_o$	New	Old	New	Old	
Air.....	AcA and AcB	0.002	0.002	4.35	1.55			(36)
Air.....	ThA and ThB	0.002	0.002	4.35	1.55			(39)
Air.....	RaA and RaB	0.002	0.002	4.35	1.55			(39)
Air.....	$\text{C}_2\text{H}_2$	0.002	0.03	1.80	1.80	>*	>*	(40)
Air.....	A	0.005	0.013	1.80	1.36	1.80	1.80	(37)
Air.....	$\text{CO}_2$	0.005	0.02	1.80	1.36	1.80	1.80	(35)
Air†.....	Air	0.008	0.013	1.80	1.35	1.80	1.80	(149)
Air.....	$\text{H}_2$	0.008	0.013	1.80	1.36	>*	>*	(37)
Air.....	Pt	0.03	0.03	1.80	1.36	1.80	1.80	(34, 38)
Air.....	Air	0.03	0.10	1.89	1.36	1.89	1.89	(33)
Air.....	Air and $\text{C}_2\text{H}_2$	0.03	0.10	1.89	1.89	>*	>*	(40)
$\text{O}_2$ .....	$\text{O}_2$	0.03	0.10	1.89	1.36	1.89	1.89	(33)
$\text{N}_2$ .....	$\text{N}_2$	0.03	0.10	1.89	1.36	1.89	1.89	(33)
Air and $\text{NH}_3$	Air	0.06	0.06	1.89	1.89	1.89	1.89	(41)
$\text{He} \dagger$ .....	He	0.001	0.010	8.70	5.13			(152)
$(\text{C}_2\text{H}_5)_2\text{O} \dagger$	$(\text{C}_2\text{H}_5)_2\text{O}$	0.005	0.02	0.22	0.19	0.22	0.22	(79)

\* The > indicates that negative ion is slightly faster than initial positive ion. † Mobility of ( $k'$ ) measured at  $P = 5$  to 50 mm and reduced to  $P = 760$  mm by equation  $k = k'P/760$ .



TABLE 6.—DIFFUSIVITY ( $\Delta$ ) OF NORMAL IONS

For methods of measurements and discussion of relation of  $\Delta$  and  $k$ , see (47, 84, 97, 133, 139)

$\frac{dN}{dt} = -\Delta \frac{dn}{dz} dx dy$ ;  $dN$  = resultant number of ions, of the species considered, which diffuses, in the direction of increasing  $z$ , through the area  $dx dy$  in the time  $dt$ , when the gradient of the concentration ( $n$ ) of these ions normal to  $dx dy$  is  $dn/dz$ ;  $n$  = number per unit of volume. For these data,  $P\Delta$  for a given gas and a given species of ion is essentially a constant; all observations were made near room temperature. At  $P = A_n$ ,  $\theta = 0^\circ\text{C}$ , and for any given gas and species of ion  $\Delta/k_0 = A_n/n_0e = 7.85 \times 10^{-5}$  erg/es;  $k_0$  = mobility constant of the ion considered;  $n_0$  = Loschmidt's number;  $e$  = electronic charge. Sign of ion is indicated by subscript + or -. Unit of  $\Delta = 0.01 \text{ cm}^2/\text{sec}$ ; of  $P = 1 \text{ mm of Hg}$ ; of temperature ( $\theta$ ) =  $1^\circ\text{C}$ .

Dry gases					
Gas	$P$	$\Delta_+$	$\Delta_-$	$\theta$	Lit.
Air	1128	2.2	2.7		(127)
Air	772	3.17	4.29	19	(138)
Air		2.90*	4.48*		(47)
Air	760	3.2	4.2		(127)
Air	758	3.2	4.2		(127)
Air	550	4.20	5.42	18	(138)
Air	400	5.78	7.80	16	(138)
Air	300	7.86	10.3	13	(138)
Air	200	11.8	15.5	12	(138)
N <sub>2</sub>	1302	1.7	2.6		(127)
N <sub>2</sub>	1120	2.0	2.8		(127)
N <sub>2</sub>	1000	2.3	3.14		(127)
N <sub>2</sub>	760	2.9	4.1		(127)
N <sub>2</sub>	760	2.95	4.14		(127)
O <sub>2</sub>	760	3.0	4.1		(127)
CO <sub>2</sub>	760	2.5	2.6		(127)

## Effect of moisture (139)

Gas	$\Delta_+$		$\Delta_-$	
	Dry	Moist	Dry	Moist
Air	2.8	3.2	4.3	3.5
O <sub>2</sub>	2.5	2.88	3.96	3.58
CO <sub>2</sub>	2.3	2.45	2.6	2.55
H <sub>2</sub>	12.3	12.8	19.0	14.2

\* Estimated correct within 6 %.

TABLE 7.—COEFFICIENT ( $\alpha$ ) OF RECOMBINATION OF NORMAL IONS: ONE PRESSURE AND ROOM TEMPERATURE

$\frac{dn}{dt} = \alpha n_+ n_-$ ;  $n_+$ ,  $n_-$  = number of + ions and - ions, respectively, per  $\text{cm}^3$ ;  $n$  = either  $n_+$  or  $n_-$ ;  $t$  = time, in seconds. Unit of pressure ( $P$ ) = 1 mm of mercury; of  $\alpha = 10^{-6} \text{ cm}^3 \text{ per (ion sec)}$ .

Gas	$P$	$\alpha$				
Air	760	1.63	1.50	1.72	1.89	1.61
O <sub>2</sub>	760	1.61				
H <sub>2</sub>	760	1.49				1.40
CO	757			0.87		
CO <sub>2</sub>	760	1.67	1.62	1.67	2.33	1.66
CH <sub>3</sub> I	28				0.56	
C <sub>2</sub> H <sub>5</sub> Cl	100				1.35	
C <sub>2</sub> H <sub>5</sub> Br	28				0.69	
(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> O	95				1.51	
N <sub>2</sub> O	749			1.35		
SO <sub>2</sub>	680			1.31		
Lit.		(137)	(60)	(132)	(106)	(91*)

\* McClung used  $\alpha$ -particles from radium.

TABLE 8.—COEFFICIENT ( $\alpha$ ) OF RECOMBINATION OF NORMAL IONS: VARIATION WITH PRESSURE ( $P$ ) (cf. TABLE 7)

For methods of measurement and discussion of observations, see also (29, 53, 61, 91, 105, 106, 120, 123, 135, 137). Unit of  $P = 1 \text{ mm of Hg}$ ; of  $\alpha = 10^{-6} \text{ cm}^3 \text{ per (ion sec)}$ .

$P$	$\alpha$	$P$	$\alpha$	$P$	$\alpha$
Air (60)		Air (53).—(Cont'd)		CO <sub>2</sub> (132).—(Cont'd)	
152	0.28	250	0.99	729	1.64
375	0.67	450	1.26	CO (132)	
760	1.50	760	1.57	247	0.22
1 550	1.7	(120)		409	0.44
2 320	1.5	280	1.77	556	0.62
3 800	1.0	420	1.85	690	0.76
(132)		540	2.05	757	0.87
197	0.44	745	2.13	SO <sub>2</sub> (132)	
307	0.73	CO <sub>2</sub> (60)		83.5	0.26
363	0.82	135	0.18	200	0.42
462	1.02	352	0.88	338	0.72
644	1.44	550	1.20	444	0.91
662	1.47	758	1.60	504	1.07
743	1.66	1 560	1.47	680	1.31
(53)		2 380	0.98	N <sub>2</sub> O (132)	
10	0.48	(132)		200	0.33
20	0.55	175	0.49	294	0.53
35	0.60	265	0.67	430	0.81
50	0.63	373	0.92	596	1.13
100	0.74	498	1.19	749	1.33
150	0.84	614	1.44		

TABLE 9.—COEFFICIENT ( $\alpha$ ) OF RECOMBINATION OF NORMAL IONS: VARIATION WITH TEMPERATURE (cf. TABLE 7)

Data for variation with temperature are very discordant. For relative values for CO<sub>2</sub> and H<sub>2</sub>, see (30). Following values are for air at constant density ( $\alpha_d$ ) and at constant pressure ( $\alpha_p$ ); the latter are relative to  $\alpha = 1.7 \times (10)^{-6} \text{ cm}^3 \text{ per (ion sec)}$  at  $289^\circ\text{K} = 16^\circ\text{C}$ . Unit of  $\alpha_d$  and  $\alpha_p = 10^{-6} \text{ cm}^3 \text{ per (ion sec)}$ ; temperature =  $T, ^\circ\text{K}$ .

$T$	94	205	285	289	337	373	428	449	546	Lit.
$\alpha_d$	2.55	1.92	1.18		0.78	0.59	0.47			(29)
$\alpha_p$				1.7		0.85	0.68	0.61	0.30	(105)

TABLE 10.—MOBILITY ( $k$ ) OF SLOW IONS

Moist air at pressure = 1 atmosphere;  $p$  = partial pressure of water vapor present. Sign of ion is indicated by subscript + or -. (For classification of slow ions, see p. 110.) Unit of  $k = 10^{-4} \text{ cm}^2/(\text{volt sec})$ ; of  $p = 1 \text{ mm of Hg}$ ; temperature =  $t, ^\circ\text{C}$ .

$p$	$k$	$p$	$k$	$p$	$k_+$	$k_-$	$t$
Ions of Type I (107), $t = 20^\circ\text{C}$				Ions of Type II.—(Cont'd)			
0.67	7.99	11.80	3.67*	10.82		189	20.9
5.87	6.85	14.90	3.25	14.18	187		24.5
8.85	4.33*	15.51	3.17	6.66		183	15.3
10.24	3.90*	16.05	3.10	13.29	181		20.4
11.11	3.79*			11.29	178		20.1
* A single measurement.				14.11	166		21.6
$p$	$k_+$	$k_-$	$t$	15.66	158		23.9
Ions of Type II (108)				15.43	153		22.6
0.78	668		21.8	13.16	146		21.0
0.73	658		20.8	15.58	116		24.3
0.68		568	19.7	14.40	110		24.2
4.97		257	18.4	13.89	91		22.1
7.33	207		24.8	14.35		81	22.2
5.92		233	20.0	15.43		73.8	22.2
6.41		189	21.3	16.67		71.5	24.5
11.67		202	20.9				



TABLE 10.—(Continued)  
Ions of Type II.—(Cont'd)

$p$	$k_+$	$k_-$	$l$	$p$	$k_+$	$k_-$	$l$
14.87		64.1	23.4	16.88	28.6		19.5
14.06	63.6		22.8	17.09	24.6		19.7

Heterogeneous Slow Ions<sup>(8)</sup>

Source is hot Pt. Air is saturated with water vapor;  $k$  refers to the type of ion that is the most numerous. Unit of  $k = 10^{-2}$  cm<sup>2</sup>/(volt sec); of age = 1 sec.

Age.	2	4	6	8	12	16	22	32	45	58	70
$k$	6	4.2	2.9	2.6	2.3	2.0	1.6	1.2	0.9	0.75	0.65

TABLE 11.—MIGRATIONAL ( $v$ ) AND THERMAL ( $u$ ) VELOCITIES OF ELECTRONS IN GASES AT 15°C

If  $k$  = mobility of electrons in the gas considered,  $v = kF$ , where  $F$  = strength of the electric field; the velocity of agitation  $u = 1.15c(10)^7$  cm/sec, where  $c^2$  is determined from the lateral scattering of a beam of electrons in an electric field due to diffusion (see (139)); the mean free path ( $l$ ) of the electrons is that defined (139) by  $v = 0.815eFl/\mu u$ ;  $l_1$  is the value of  $l$  when pressure ( $P$ ) is 1 mm of Hg, and temperature = 15°C; in the units named below,  $l_1 = 0.0797vcP/F$ . For actual values of  $F$  and  $P$ , see original papers. Unit of  $F = 1$  volt/cm; of  $P = 1$  mm of Hg; of  $l_1 = 0.01$  cm; of  $v = 10^6$  cm/sec; of  $k = 10^3$  cm<sup>2</sup>/(volt sec);  $c$  is dimensionless;  $u = 1.15c(10)^7$  cm/sec.

A (141); 10 < F < 50; 2 < P < 150				He (142).—(Continued)			
F/P	$v$	$c^2$	$l_1$	F/P	$v$	$c^2$	$l_1$
15.00	82.0	324	7.92	2.0	12.7	105.0	5.25
10.00	65.0	324	9.42	1.5	10.5	79.5	5.0
5.00	40.0	310	11.3	1.00	8.25	53.0	4.85
1.25	7.7	320	8.88	0.50	5.74	27.0	4.8
0.950	6.00	280	8.52	0.20	3.93	11.3	5.3
0.710	4.85	240	8.52	0.10	2.96	6.20	5.95
0.525	4.15	200	9.02	0.05	2.14	3.68	6.6
0.440	3.85	180	9.44	0.02	1.33	2.12	7.8
0.355	3.6	160	10.3	0.013	1.11	1.77	9.14
0.275	3.4	140	11.8	He (78); 10 < F < 100; 100 < P < 760			
0.195	3.25	120	14.7	$k_0 = 757/[1.565 + 760F/P]$			
0.125	3.1	100	20.0	$v = 760k_0F/P$			
H <sub>2</sub> (140); 4 < F < 35; 0.6 < P < 40				N <sub>2</sub> (140); 4 < F < 34; 0.3 < P < 20			
56	248	146	4.27	60	193	126	2.89
50	217	138	4.07	50	171	108	2.83
40	166	123	3.67	40	146	89	2.75
30	106	104	2.87	30	117	72.5	2.67
20	72	78	2.53	20	86	59.5	2.66
10	40.7	44	2.15	10	48.5	48.5	2.69
5	26.7	25.5	2.14	5	27	41.3	2.77
3	20.2	18.6	2.31	3	17.8	35.5	2.82
1.5	14.4	12	2.66	2	13.1	30.5	2.88
1	11.9	9	2.86	1	8.7	21.5	3.20
0.5	9.0	5.2	3.25	0.5	6.2	13	3.55
0.25	6.5	3.1	3.64	0.25	5.15	7.5	4.50
H <sub>2</sub> (78); 10 < F < 100; 100 < P < 760				N <sub>2</sub> (78); 10 < F < 100; 100 < P < 760			
$k_0 = 432/[55.2 + F(760/P)^{3/4}]$				$k_0 = 363.7/[11.9 + 760F/P]$			
$v = 760k_0F/P$				$v = 760k_0F/P$			
He (142); 2 < F < 27; 5 < P < 240				N <sub>2</sub> (151); P = 760; alternating potential of frequency 1000n per sec.			
5.0	30.2	172.0	6.4	F	k	n	
4.0	23.5	152.0	5.85	1.01	17.9	5.30	
3.0	17.5	137.0	5.5	1.16	18.1	6.21	
2.5	15.0	124.0	5.4				

TABLE 11.—(Continued)

N<sub>2</sub> (151).—(Continued)

F	k	n
1.22	17.7	6.30
2.2	18.0	11.50
2.9	17.6	15.05
3.6	17.4	18.60
4.2	17.5	21.50
5.0	17.0	25.00
6.3	16.2	29.70
5.5	16.2	16.67
6.9	15.5	30.90
8.0	15.9	37.00
13.0	13.3	50.50
17.5	11.85	60.1
23.2	10.30	68.5
26.1	9.42	71.1
33.5	7.95	77.0
35.8	7.52	79.1
39.0	7.25	81.3
43.3	6.80	84.5
48.0	6.11	85.3
55.5	5.50	87.7

O<sub>2</sub> (140); 4 < F < 35; 1 < P < 10

F/P	$v$	$c^2$	$l$
50	201	136	3.74
20	86	70	2.89
14	61	55.5	2.57
10	46	50	2.58
6	36	45	3.22
2	30	22.5	5.6

A + H<sub>2</sub> (141); (?) < F < (?); (?) < P < (?)

96% A + 4% H <sub>2</sub>			
64.8	26.5	140	0.39
42.4	25.4	100	0.48
26.0	23.5	70	0.61
15.6	20.8	50	0.76
10.8	19.0	40	0.89
6.55	16.7	30	1.12
3.25	13.6	20	1.51
2.25	12.2	16	1.75
1.72	11.1	13	1.87
1.28	10.00	10	1.99
1.0	9.10	8	2.08
0.75	7.95	6	2.09
0.5	6.35	4	2.05

## Air (140); (?) &lt; F &lt; (?); (?) &lt; P &lt; (?)

F/P	$v$	$c^2$	$l$
100	270	160	2.72
50	173	102	2.78
20	90	57	2.71
10	52	46	2.82
5	30	38	2.96
2	17.5	22	3.28
1	12.5	11	3.30
0.5	9	5.7	3.37

For relations found with parallel plates,  $P = 40$  to 90 mm, see (75).

## NO (129); 2 &lt; F &lt; 35; 1 &lt; P &lt; 10

	$v$	$c^2$	$l$
13	84	37.0	1.42
10	74	21.7	0.88
8	66	16.7	0.73
5	51	13.3	0.84
4	45	12.2	0.97
3	38	11.0	1.10
2	30	9.3	1.21
1	22	7.0	1.37

N<sub>2</sub>O (129); 2 < F < 17; 0.6 < P < 10

	$v$	$c^2$	$l$
13.33	48	13.9	
6.66	49	9.2	
3.33	46	5.0	
1.66	32	2.70	
0.83	16.2	1.81	
0.42	7.5	1.32	

## CO (129); 2 &lt; F &lt; 35; 0.3 &lt; P &lt; 40

	$v$	$c^2$	$l$
50	152	86	2.24
40	114	68	1.87
30	80	52	1.53
20	57	42	1.47
10	38	34	1.76
5	28.5	22.7	2.16
3	26.0	16.0	2.76
2	23.0	11.0	3.04
1	18.0	5.5	3.36
0.5	13.0	4.80	4.52
0.25	9.0	3.20	5.14

## CO (150); 5 &lt; F &lt; 100; 100 &lt; P &lt; 723

$k = 1870/[P\sqrt{0.005 + (F/P)}]$   
 $v = Fk \times 10^{-3}$

TABLE 12.—NUMBER ( $N$ ) OF MOLECULAR IMPACTS OF AN ELECTRON BEFORE ITS ATTACHMENT TO FORM A NORMAL NEGATIVE ION

$N$  appears to be independent of pressure (observations from  $P = 20$  mm to  $P = 760$  mm), but increases with the initial velocity ( $v_i$ ) of the electron (see end of table). Values tabulated refer to 15°C and are rather rough approximations.  $N = A \times 10^4$  (5, 72, 77, 79, 88, 148).

Gas	A	n	Observer	Gas	A	n	Observer
A.....	=		Franck	He.....	=		Franck
Cl.....	<2.1	3	Wahlin	N.....	=		Loeb
H.....	=		Loeb	Ne.....	=		Townsend



TABLE 12.—(Continued)

Gas	A	n	Observer	Gas	A	n	Observer
O <sub>2</sub> .....	8.7	3	Loeb	C <sub>2</sub> H <sub>4</sub> .....	4.7	7	Wahlin
HCl*.....	<2	3	Loeb	C <sub>2</sub> H <sub>5</sub> Cl.....	3.7	5	Wahlin
H <sub>2</sub> S*.....	2	4	Loeb	C <sub>2</sub> H <sub>6</sub> .....	2.5	6	Wahlin
SO <sub>2</sub> *.....	<2	3	Loeb	(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> O*.....	4	4	Loeb
NH <sub>3</sub> .....	9.9	7	Wahlin	Air‡.....	1.98	5	Loeb
N <sub>2</sub> O.....	6.1	5	Loeb	Air.....	4.3	4	Loeb
CO.....	1.6	8	Wahlin	Air <sub>23</sub>   .....	3.0	5	Bailey
CO <sub>2</sub> †.....	1.5	7	Loeb	Air <sub>48</sub>   .....	5.0	5	Bailey
CO <sub>2</sub> ‡.....	2.1	5	Loeb	Air <sub>100</sub>   .....	1.4	6	Bailey
C <sub>2</sub> H <sub>2</sub> .....	7.8	6	Wahlin				

\* Values estimated relative to air, from pressure at which free electrons appear (79, 80, 88, 89). † Fresh CO<sub>2</sub>. ‡ CO<sub>2</sub>, 22 hr old. § Accurate absolute value; dry air,  $P$  between 20 and 760 mm (77). || Subscript indicates value of  $v$ ; unit =  $10^6$  cm/sec; e.g., for air<sub>23</sub>,  $v_1 = 33 \times 10^6$  cm/sec.

TABLE 13.—CONDENSATION OF VAPORS ON IONS AND NUCLEI

The degree of supersaturation ( $S$ ) of a vapor subjected to adiabatic expansion is defined as the ratio of the vapor pressure after the expansion to the pressure of the saturated vapor at the temperature of the gas after its expansion.

When water vapor is supersaturated by adiabatic expansion, four stages of condensation are recognized: Condensation occurs on dust particles and on certain products of chemical action if  $S < 4$ ; begins to occur on  $-$  ions at  $S = 4$  ca., on  $+$  ions at  $S = 6$  ca., and on uncharged water nuclei at  $S > 6$ . The nature of the gas in which the vapor is distributed has no effect upon the value of  $S$  required to initiate a given type of condensation.  $E \equiv V_2/V_1 =$  adiabatic expansion necessary to produce condensation,  $V_1[V_2] =$  volume of moist gas before [after] expansion.  $E_0, E_-, E_+ =$  value of  $E$  corresponding to condensation on uncharged water nuclei, on  $-$  ions, on  $+$  ions;  $S_0, S_-,$  and  $S_+$  are the values of  $S$  corresponding to  $E_0, E_-$ , and  $E_+$ . When the sign of the ion is not known the value of  $E$  is placed between the columns for  $E_- E_+$ .

Formula	Vapor	$E_0$	$E_-$	$E_+$	$S_+$	Lit.
H <sub>2</sub> O	Water*.....	1.38	1.25	1.31	5.8	(157)
H <sub>2</sub> O	Water.....	1.42	1.29			(28)
H <sub>2</sub> O	Water.....	1.366	1.265	1.314		(111)
H <sub>2</sub> O	Water†.....	1.31	1.270	1.32		(3)
H <sub>2</sub> O	Water.....		1.251			(58)
CCl <sub>4</sub>	Carbon tetrachloride....		1.89			(28)
CS <sub>2</sub>	Carbon disulfide.....	1.08	1.05			(28)
CS <sub>2</sub>	Carbon disulfide.....		1.02			(111)
CHCl <sub>3</sub>	Chloroform.....		1.598	1.528	3.0	(111)
C <sub>2</sub> H <sub>5</sub> I	Ethyl iodide.....		1.530	1.484		(111)
C <sub>6</sub> H <sub>5</sub> Cl	Chlorobenzene.....	1.60	1.48			(28)
C <sub>6</sub> H <sub>6</sub>	Benzene.....	1.78	1.53			(28)
C <sub>6</sub> H <sub>6</sub>	Benzene.....	1.74	1.50			(3)
C <sub>6</sub> H <sub>6</sub>	Benzene‡.....		1.642			(111)
C <sub>3</sub> H <sub>8</sub> O	Acetone.....		2.009			(111)
CH <sub>3</sub> O	Methyl alcohol.....	1.42		1.32		(28)
CH <sub>3</sub> O	Methyl alcohol.....	1.378	1.306	1.251	2.3	(111)
C <sub>2</sub> H <sub>5</sub> O	Ethyl alcohol.....	1.25		1.20		(28)
C <sub>2</sub> H <sub>5</sub> O	Ethyl alcohol.....	1.254	1.200	1.175	2.3	(111)
C <sub>2</sub> H <sub>5</sub> O	Ethyl alcohol.....	1.190	1.158	1.180		(3)
C <sub>3</sub> H <sub>7</sub> O	<i>n</i> -Propyl alcohol.....	1.237	1.201	1.178	3.1	(111)
C <sub>4</sub> H <sub>9</sub> O	Isobutyl alcohol.....	1.260	1.215	1.198	3.6	(111)
C <sub>6</sub> H <sub>12</sub> O	Isoamyl alcohol.....	1.293	1.233	1.218	5.5	(111)
C <sub>6</sub> H <sub>12</sub> O	Isoamyl alcohol.....			1.182	4.1	(58)
C <sub>6</sub> H <sub>12</sub> O	<i>n</i> -Amyl alcohol.....	1.354	1.307	1.271		(111)
C <sub>7</sub> H <sub>15</sub> O	Heptyl alcohol.....	1.362	1.306	1.269		(111)
CH <sub>2</sub> O <sub>2</sub>	Formic acid.....			1.782	25.1	(58)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Acetic acid.....			1.441	9.3	(58)
C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	Propionic acid.....			1.343	9.4	(58)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	<i>n</i> -Butyric acid.....			1.380	15.0	(58)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Isobutyric acid.....			1.360	13.3	(58)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Isovaleric acid.....			1.220	6.0	(58)
C <sub>5</sub> H <sub>8</sub> O <sub>2</sub>	Ethyl acetate.....			1.486	8.9	(58)

TABLE 13.—(Continued)

Formula	Vapor	$E_0$	$E_-$	$E_+$	$S_+$	Lit.
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Methyl <i>n</i> -butyrate.....			1.334	5.3	(58)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Methyl isobutyrate.....			1.347	5.2	(58)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Ethyl propionate.....			1.414	7.8	(58)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	<i>n</i> -Propyl acetate.....			1.310	5.0	(58)

\* For H<sub>2</sub>O,  $S_0 = 7.9$ ,  $S_- = 4.15$  (157). † For H<sub>2</sub>O,  $S_0 = 6$  (3). ‡ For C<sub>6</sub>H<sub>6</sub>, ions of unknown sign,  $S = 4.3$  (111).

### EFFECTIVE SECTIONAL AREA OF MOLECULES\* (1, 2, 11, 12, 13, 14, 15, 16, 17, 48, 54, 64, 65, 66, 93, 95, 113, 114, 115, 116, 117, 119, 121, 130, 161, 162)

When a beam of electrons passes through a gas, the number ( $n_x$ ) of electrons remaining in the beam after it has gone a distance  $x$  is given by the equation,  $n_x = n_0 e^{-qpx}$ , where  $p$  is the pressure of the gas. If the cross-sectional area of an electron is negligible as compared with that of a molecule, and if the velocities of the molecules are negligible, as compared with that of the electron, then  $qp$  will be the sum of the cross-sectional areas of all the molecules in a unit volume. By definition the mean free path of an electron,  $L_e$  is defined as  $1/qp$ . If the effective cross-sectional area of a molecule for an encounter with another molecule were the same as that for an encounter with an electron, then we would have  $L_e = 4\sqrt{2}L$ , where  $L$  is the mean free path of the molecule in the gas.† It is found that  $qp$  varies with the velocity of the electrons and that  $1/qp$  or  $L_e$  is not equal to  $4\sqrt{2}L$ . (It should be noticed that  $L_e$  is not the same quantity as that denoted by  $l$  in Table 11.) The absorbing cross-section of all the molecules in a unit volume of gas at the temperature  $t$  and at unit pressure is  $q$ . The effective radius,  $r$ , of the absorbing cross-section of a single molecule is given by the equation  $\pi r^2 = q/N_t$ , where  $N_t$  is the number of molecules per unit volume at the temperature  $t$  and at unit pressure. For electrons with high velocities ( $\beta$ -rays),  $q$  has such a value that  $r$  is of the same order of magnitude as the radius of the nucleus, as deduced from the scattering of  $\alpha$ -particles. In actual measurements, the beam of electrons must have a finite width, and, consequently, those electrons that have been deviated from their initial path by less than a certain amount, determined by the apparatus used, are not eliminated from the beam. This source of error makes the computed value of  $q$  too small, and causes the results of different observers to differ slightly. In most cases, the deviation of an observer's separate determinations from the mean curve representing all his values is less than 10%.

Typical data are shown in Figs. 10 to 14:

Molecule.....	A	Cd	CH <sub>4</sub>	CO	CO <sub>2</sub>	H <sub>2</sub>	He	Hg
Figures.....	10	14	11	12	13	11	11	14

Molecule.....	Kr	N <sub>2</sub>	NO	N <sub>2</sub> O	Ne	O <sub>2</sub>	Xe	Zn
Figures.....	10	12	13	13	10	13	10	14

\*In collaboration with R. B. Brode.

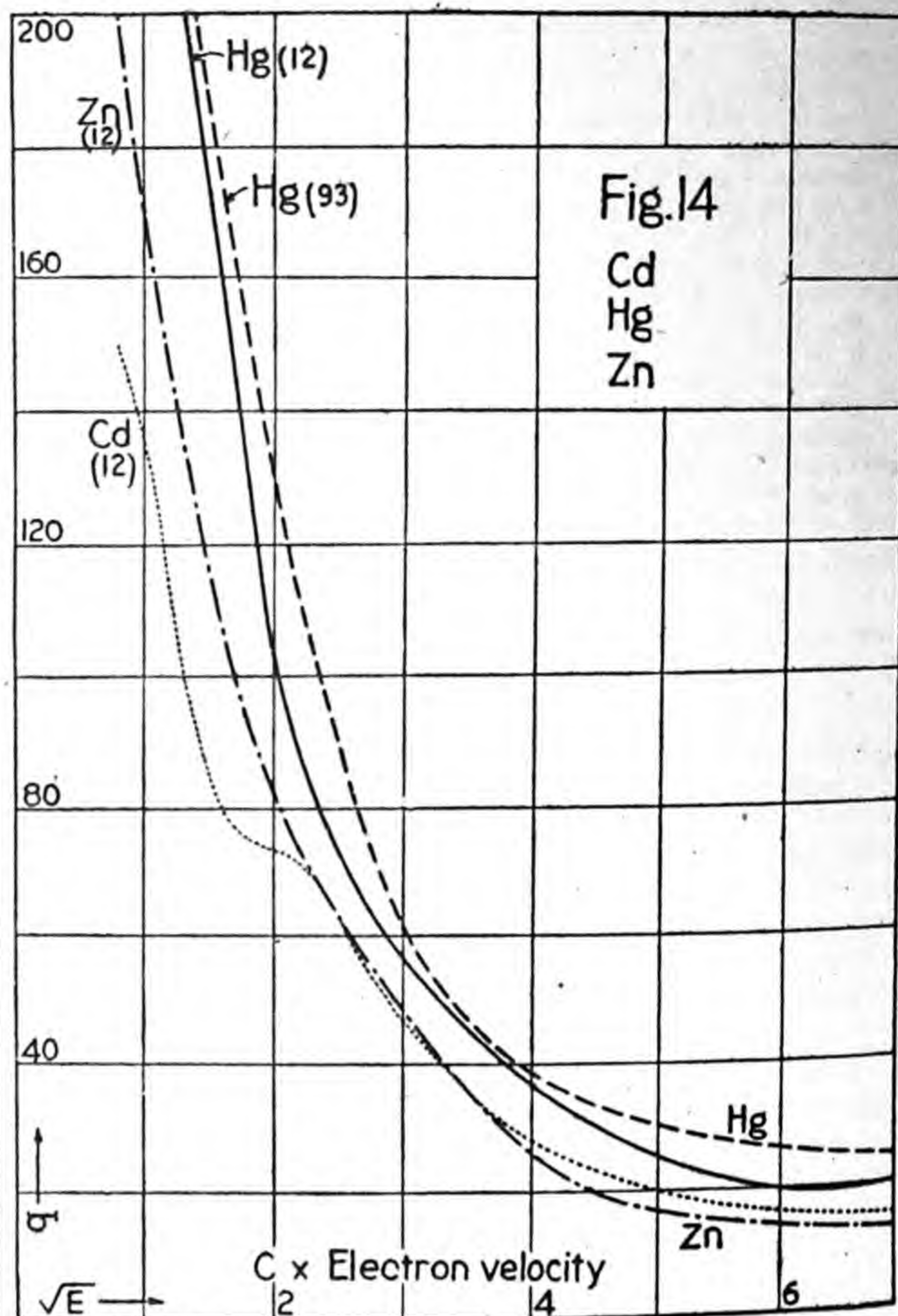
†In figures, short line followed by symbol for gas on axis of ordinates indicates gas kinetic value,  $4\sqrt{2}L$ .

### LITERATURE

(For a key to the periodicals see end of volume)

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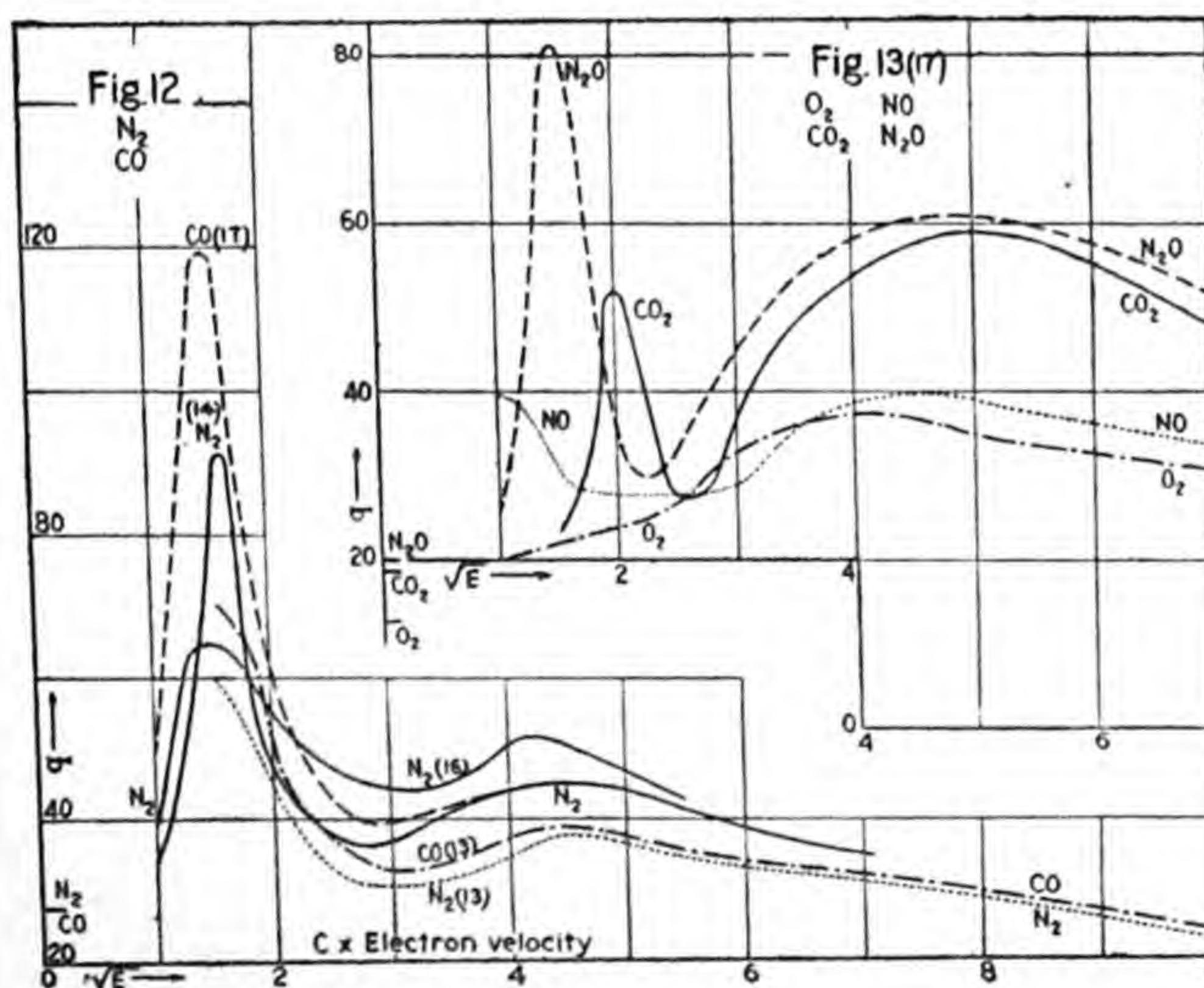




FIGS. 10 to 14.—Effective sectional areas of molecules.

FIGS. 10 to 14.—Effective sectional areas of molecules. (For general discussion and index, see p. 117.) These curves represent typical values deduced from electronic data.  $q$  = sum of the effective absorbing cross-sectional areas of all the molecules contained in a unit volume of the gas at 0°C and a pressure of 1 mm Hg; unit of  $q$  = 1 cm<sup>2</sup> per cm<sup>3</sup>. The velocity of the electrons is indicated by numbers equal to the square root of the voltage through which the electron has been accelerated. The equation connecting velocity ( $v$ ) and volts ( $V$ ), for slow electrons only, is  $\frac{1}{2}mv^2 = eV$ , or  $v = 0.595 \times 10^8 \sqrt{V}$  cm/sec, where  $m$  is the mass of an electron and  $e$  its charge.

For some gases, the corresponding sum of the cross-sectional areas involved in the molecular encounters considered in the kinetic theory of gases is indicated by a short dash at the axis of ordinates. Literature references are enclosed in ( ).



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## IONIZATION OF GASES

O. STUHLMAN, JR.

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Ionization by electrons in field of zero intensity.	Ionisation par les électrons dans un champ d'intensité zéro.	Ionisation durch Elektronen in einem Felde von der Stärke Null.	Ionizzazione per mezzo di elettroni di un campo di intensità zero.	
Variation with velocity.	Variation avec la vitesse.	Änderung mit der Geschwindigkeit.	Variazione con la velocità.	
Air.	Air.	Luft.	Aria.....	120
Other gases.	Autres gaz.	Andere Gase.	Altri gas.....	120
Relative molecular ionization.	Ionisation moléculaire relative.	Relative molekulare Ionisation.	Ionizzazione molecolare relativa.....	121
Total number of ions.	Nombre total des ions.	Gesamtanzahl der Ionen.	Numero totale degli ioni	121
Ionization by electrons in fields of finite intensity.	Ionisation par les électrons dans des champs d'intensité finie.	Ionisation durch Elektronen in Feldern bestimmter Intensität.	Ionizzazione per mezzo di elettroni in campi di intensità finita.	
Variation with intensity of field.	Variation avec l'intensité du champ.	Änderung mit der Intensität des Feldes.	Variazione con l'intensità del campo.....	121
Variation with pressure.	Variation avec la pression.	Änderung mit dem Drucke.	Variazione con la pressione.....	121
Energy expended by electron in ionizing a molecule.	Énergie dépensée par l'électron en ionisant une molécule.	Energieaufwand bei der Ionisation eines Moleküls durch Elektronen.	Energia spesa da un' elettrone per ionizzare una molecola.....	121
Ionization by positive ions.	Ionisation par les ions positifs.	Ionisation durch positive Ionen.	Ionizzazione per mezzo di ioni positivi.	
Variation with velocity: $\alpha$ -particles in air.	Variation avec la vitesse: particules $\alpha$ dans l'air.	Änderung mit der Geschwindigkeit: $\alpha$ -Partikeln in Luft.	Variazione con la velocità: particelle $\alpha$ nell'aria.....	122
Relative molecular and total ionization: $\alpha$ -particles.	Ionisation moléculaire relative et ionisation totale: particules $\alpha$ .	Relative molekulare und totale Ionisation: $\alpha$ -Partikeln.	Ionizzazione relativa molecolare e totale: particelle $\alpha$ .....	122
By positive residues: variation with intensity of field.	Par les résidus positifs: variation avec l'intensité du champ.	Durch positive Rückstände: Änderung mit der Intensität des Feldes.	Ionizzazione per mezzo dei residui positivi: variazione con l'intensità del campo.....	122
Atomic ionization relative to air.	Ionisation atomique relative à l'air.	Atomionisation in Beziehung auf Luft.	Ionizzazione atomica relativa all'aria.....	122
Ionization by $\gamma$ - and X-rays: relative molecular.	Ionisation par les rayons $\gamma$ et par les rayons X: moléculaire relative.	Ionisation durch $\gamma$ -Strahlen und Röntgenstrahlen: Relative molekulare.	Ionizzazione per mezzo di raggi $\gamma$ e X: molecolare relativa.....	123
Ionization by secondary X-rays: relative molecular and total.	Ionisation par les rayons X secondaires: moléculaire relative et totale.	Ionisation durch sekundäre Röntgenstrahlen: Relative molekulare und vollständige.	Ionizzazione per mezzo di raggi X secondari: molecolare relativa e totale.	123
Energy expended in ionizing air by X-rays.	Énergie dépensée en ionisant l'air par les rayons X.	Energieaufwand bei der Ionisation der Luft durch Röntgenstrahlen.	Energia spesa per ionizzare l'aria con i raggi X.....	123
Ionization of gases by phosphorus (P).	Ionisation des gaz par le phosphore (P).	Ionisation der Gase durch Phosphor (P).	Ionizzazione dei gas per mezzo del fosforo (P)...	124



This section includes ionization by impact of electrons, of positively charged residues, and of  $\alpha$ -particles, by electromagnetic radiation and by chemical action. Data for the conductivity of flames, for ionization potentials, and for photoelectric thresholds are given elsewhere; consult p. 156, 69 and 67, respectively.

The following symbols will be used:

$c$	velocity of light in vacuum.
$C$	Coefficient of ionization; $n = Cp/T$ .
$C_r$	$C_1/C_2$ for the same ionizing radiation (corpuscular or electromagnetic) = coefficient of relative molecular ionization of gas (1) with reference to gas (2).
$E_i$	Energy expended in producing one pair of ions.
$E_1$	Kinetic energy possessed by the charged particle at the beginning of its ionizing career.
$e$	Electronic charge.
$-i$	$\alpha/p$ ; $+i = \beta/p$ .
$-I$	$\int_0^\infty -idx$ ; $+I = \int_0^\infty +idx$ .
$-Np[+Np]$	Number of encounters of an electron [a + ion] per cm of its path; the superior $[+]$ may be omitted where convenient.
$n$	Number of ions produced per sec in 1 cm <sup>3</sup> of a thin layer of gas at pressure $p$ and absolute temperature $T$ .
$p$	Pressure of the gas being ionized.
$p_m$	Pressure at which $\alpha$ is a maximum for a given $X$ .
$V$	Potential difference required to confer the energy $E$ upon a charge = $e$ ; $eV_1 = E_1$ , $eV_i = E_i$ , etc.
$v$	Velocity of the ionizing particle.
$X$	Intensity of the applied electric field.
$\alpha[\beta]$	Number of pairs of ions produced per cm of path by each electron [each + ion].
$\lambda$	Wave-length of the exciting radiation.

If the density of the gas remains constant,  $\alpha$ ,  $\beta$  and the number of ions produced per sec by a given electromagnetic radiation are all independent of the temperature (10, 11, 14, 32, 33, 44); tested (10) from  $-180$  to  $+1600^\circ\text{C}$ . If the velocity of the particles arises solely from  $X$ , then, for a given temperature and gas,  $\alpha/p$  and  $\beta/p$  depend solely upon  $X/p$  (63, 65, 66, 67, 69). If  $X$  is so great that the effects of thermal agitation may be neglected,  $\alpha = N_p e^{-N_p V_i/X}$  (63); hence  $(\alpha_{\max.})_p \text{ const.} = Np$  and  $(\alpha_{\max.})_X \text{ const.}$  occurs when  $p (=p_m) = X/NV_i$  or  $X/p_m = NV_i$ ; the value of  $N$  is determined from that of  $(\alpha_{\max.})_p$ .

For expressions for the total current resulting from ionization by both electrons and positive residues, see (3, 63); for ionization of mixed gases, see (3, 26); for theory, see Bohr (5, 6) and Fowler (19, 20).

TABLE 1.—IONIZATION OF AIR BY ELECTRONS: VARIATION WITH VELOCITY (4, 15, 16, 27, 71)

$V_1 = 5.082 \times 10^6 \left\{ \frac{1}{\sqrt{1 - (v/c)^2}} - 1 \right\}$  volt. For  $V_1 < 4000$  volt,  $v/c$  has been computed from observed value of  $V_1$  by means of the approximate relation  $v/c = 0.001983\sqrt{V_1}$ ,  $V_1$  being expressed in volts; the corresponding expression for  $E_1$  is  $E_1 = 1.592V_1 \times 10^{-12}$ . Unit of  $\alpha = 1$  per cm; of  $p = 1$  mm of Hg; of  $V_1 = 1$  volt;  $V_1 = A \times 10^a$ .

$A$	$n$	$100v/c$	$\alpha/p$	$A$	$n$	$100v/c$	$\alpha/p$
		100	0.054	4.63	4	40	0.32
1.12	6	95	0.063	2.45	4	30	0.42
6.57	5	90	0.073	1.53	4	24	0.43*
3.39	5	80	0.092	1.05	4	20	1.04
2.03	5	70	0.125	9.42	3	19	1.14
1.27	5	60	0.173	8.43	3	18	1.25
7.86	4	50	0.242	7.50	3	17	1.38

TABLE 1.—(Continued)

$A$	$n$	$100v/c$	$\alpha/p$	$A$	$n$	$100v/c$	$\alpha/p$
6.63	3	16	1.50	7.00	2	5.246	6.19
5.82	3	15	1.68	6.00	2	4.857	5.43
4.77	3	13.6	2.01	4.94	2	4.407	6.43
2.225	3	9.353	3.46	3.97	2	3.951	7.84
1.808	3	8.432	4.98	3.72	2	3.825	9.18
1.500	3	7.680	6.96	3.47	2	3.694	9.36
1.400	3	7.420	7.85	2.95	2	3.406	9.12
1.200	3	6.869	10.32	2.47	2	3.116	13.8
1.105	3	6.601	12.04	1.98	2	2.790	14.6
1.050	3	6.425	12.85	1.56	2	2.477	23.6
9.92	2	6.246	13.82	1.22	2	2.190	37.8
9.85	2	6.223	13.91	8.4	1	1.82	51.4
9.72	2	6.183	13.69	4.7	1	1.36	95.0
9.52	2	6.118	13.50	4.1	1	1.27	111.2
9.05	2	5.965	12.36	3.5	1	1.17	108.2
8.90	2	5.916	10.14	2.8	1	1.05	82.7
8.00	2	5.609	6.72	1.8	1	0.841	51.2

\* This value (15) seems to be much too small; it is the only value available between  $v/c = 0.20$  and  $v/c = 0.30$ .

TABLE 2.—IONIZATION OF GASES BY ELECTRONS: VARIATION WITH VELOCITY (34)

For air,  $v > 0.025c$ , see Table 1. ( $v$  is computed from Einstein's formula,  $m_0 c^2 \left( \frac{1}{\sqrt{1 - (v/c)^2}} - 1 \right) = V_1 e$ . Unit of  $V_1 = 1$  volt; of  $\alpha = 1$  per cm; of  $p = 1$  mm of Hg. Error  $\leq 4\%$ .)

Gas	$A$	$H_2$	He	$N_2$	Ne	$CH_4$	$CO^*$
$V_1$	$100v/c$	$\alpha/p$					
300	3.44	4.14	1.264	0.648	4.460	1.502	4.36
280	3.33	4.54	1.362	0.699	4.775	1.557	4.72
260	3.20	4.83	1.463	0.744	5.100	1.608	5.05
240	3.09	5.31	1.568	0.782	5.420	1.666	5.41
220	2.96	5.68	1.678	0.815	5.650	1.710	5.74
200	2.80	6.03†	1.785	0.844	6.080	1.754	6.20
180	2.67	6.36	1.902	0.867	6.425	1.800	6.43
160	2.52	6.67	2.018	0.880	6.780	1.828	6.78
140	2.36	6.95	2.137	0.881	7.125	1.820	7.14
120	2.18	7.21	2.260	0.870	7.450	1.768	7.47
100	1.99	7.45	2.376	0.846	7.640	1.651	7.82
80	1.78	7.65	2.487	0.804	7.470	1.450	8.06
60	1.54	7.48	2.518	0.730	6.880	1.130	7.80
40	1.25	6.74	2.280	0.500	5.580	0.630	6.79
35	1.17	6.36	2.153	0.380	4.96	0.480	6.28
30	1.08	5.56	1.947	0.229	4.09	0.320	5.55
29	1.06	5.35	1.882	0.192	3.89	0.287	5.37
28	1.04	5.13	1.825	0.155	3.68	0.255	5.20
27	1.02	4.88	1.755	0.120	3.47	0.220	5.00
26	1.00	4.61	1.670	0.082	3.24	0.180	4.80
25	0.98	4.31	1.600		3.02	0.140	4.55
24	0.96	4.00	1.500		2.80	0.095	4.30
23	0.94	3.67	1.383		2.54	0.044	4.02
22	0.92	3.30	1.260		2.28		3.72
21	0.90	2.90	1.130		2.00		3.40
20	0.88	2.45	0.980		1.72		3.05
19	0.85	1.90	0.800		1.42		2.67
18	0.83	1.29	0.595		0.80		2.26
17	0.81	0.45	0.350				1.80
16	0.79						1.28
15	0.76						0.75
14	0.73						0.10

\* Jesse (35). † Corresponds to  $V_1$  midway between bracketed lines. ‡ Jesse (35) found 6.44.



TABLE 3.—RELATIVE MOLECULAR IONIZATION OF GASES BY  $\beta$ -RAYS FROM VARIOUS SUBSTANCES

$n_r = n/n_a = C_r p T_a / p_a T$ ;  $n_a$ ,  $p_a$ ,  $T_a$  refer to air;  $p_a = 760$  mm Hg; values of  $C_r$

Gas	U-X (37, 38)	Ra (60)	Ac (37, 38)
Air.....	1.00	1.00	1.00
H <sub>2</sub> .....	0.165*	0.157	0.159
O <sub>2</sub> †.....	1.17	1.21	
SO <sub>2</sub> .....	2.25	2.31	
N <sub>2</sub> O†.....	1.55		
NH <sub>3</sub> †.....	0.89		
CO <sub>2</sub> †.....	1.60*	1.57	
CCl <sub>4</sub> .....	6.28	5.83	
CS <sub>2</sub> .....	3.62		
C <sub>2</sub> N <sub>2</sub> .....		1.86	
CHCl <sub>3</sub> .....	4.94	4.89	
CH <sub>3</sub> Br.....	3.73		
CH <sub>3</sub> I.....	5.11	5.18	5.34
CH <sub>3</sub> O.....	1.69		
C <sub>2</sub> H <sub>5</sub> O†.....	2.12		
C <sub>2</sub> H <sub>5</sub> Br.....	4.41		4.43
C <sub>2</sub> H <sub>5</sub> Cl.....	3.24		3.33
C <sub>2</sub> H <sub>5</sub> I.....	5.90		
C <sub>4</sub> H <sub>10</sub> O§.....	4.39		4.28
C <sub>6</sub> H <sub>12</sub>   .....	4.55		
C <sub>6</sub> H <sub>6</sub> ¶.....	3.95		

\* Bloch (4) finds: H<sub>2</sub>, 0.13; CO<sub>2</sub>, 1.59; illuminating gas (40 % H<sub>2</sub>), 0.63<sub>4</sub>

† Commercial purity.

‡ Acetaldehyde. || Pentane.

§ Ethyl ether. ¶ Benzene.

TABLE 4.—TOTAL NUMBER ( $I$ ) OF PAIRS OF IONS PRODUCED BY AN ELECTRON IN FIELD OF ZERO INTENSITY

$I = \int_0^\infty idz$ , where  $i = \alpha/p$ . If  $0.6 < 100v/c < 2.8$ ,  $I = c_1 (V - c_2)$ ;  $c_2$  is not  $V_1$ , cf. Table 7. Unit of  $\alpha = 1$  per cm; of  $p = 1$  mm of Hg; of  $V$  and  $c_2 = 1$  volt; of  $I = 1000$ ; of  $c_1 = 1$  per volt.

Air: various $\beta$ -rays				Slow electrons (36)		
Rays	$\alpha/p$	$I$	Lit.	Gas	$c_1$	$c_2$
Ac-C''.....	0.174	10	(24)	H <sub>2</sub> .....	0.0258	11
Th-C''.....	0.174	17	(24)	He.....	0.0244	20
Ra-B.....	0.171	3.7	(24)	N <sub>2</sub> .....	0.0276	12
Ra-C.....	0.138	7.7	(24)	O <sub>2</sub> .....	0.0275	11
		12	(18)			
Ra-E.....	0.088	3.3	(24)			
U-X.....	0.099	11.3	(24)			

TABLE 5.—IONIZATION OF GASES BY ACCELERATED ELECTRONS: VARIATION WITH INTENSITY ( $X$ ) OF FIELD

For ionization and conductivity of mixed gases, see (3). For certain gases  $\frac{\alpha}{p} = a \left( \frac{X}{p} - \frac{X_i}{p} \right)^b$ , where  $X_i$  is weakest field in which ionization occurs (3);  $X_i/p = -NV_i$ . Unit of  $X = 1$  volt/cm; of  $p = 1$  mm of Hg; of  $\alpha = 1$  per cm.

$X/p$	$\alpha/p$				
	A	H <sub>2</sub> *	H <sub>2</sub>	He	He
600	9.2				
500	8.5				
400	7.5				
300	6.2		3.7		
200	4.4		3.3		
100	2.0		2.62	2.37	
70			1.36	1.98	
60		0.62	0.76	1.65	
		0.43	0.59	1.50	1.35

TABLE 5.—(Continued)

$X/p$	$\alpha/p$				
	A	H <sub>2</sub> *	H <sub>2</sub>	He	He
50	0.58	0.27	0.36	1.31	1.20
40		0.14	0.21	1.10	1.00
30		0.04	0.08	0.86	0.77
25		0.015			
22.5		0.006			
20	0.05			0.57	0.40
15				0.42	
10				0.28	0.12
5				0.12	
Lit.	(25, 63)	(3)	(63)	(26)	(63)

$X/p$	$\alpha/p$				
	N <sub>2</sub>	H <sub>2</sub> O	HCl	CO <sub>2</sub> †	Air‡
1500			17.5		
1200				13.7	
1000		9.7	15.4	12.6	10.5
900		9.4			
800		9.0	14.0	11.0	9.3
700		8.5	13.0	10.2	8.7
600	7.0	7.95	11.9	9.1	7.9
500	6.2	7.2	10.5	7.8	7.0
400	5.2	6.35	8.9	6.4	5.82
300	3.95	5.2	6.8	4.8	4.4
200	2.3	3.6	4.1	2.8	2.6
100	4.2	1.31	1.21	0.82	0.72
70				0.27	0.17
60				0.17	0.078
50				0.079	0.029
40				0.020	
Lit.	(63)	(63)	(63)	(3, 63)	(3, 63, 64, 66)

\*  $a = 266.7 \times 10^{-6}$ ,  $b = 1.615$ ,  $X_i/p = 200$ ; if  $200 \leq X/p \leq 685$  (3).

†  $a = 402.9 \times 10^{-6}$ ,  $b = 1.515$ ,  $X_i/p = 356$ ; if  $356 \leq X/p \leq 755$  (3).

‡  $a = 159.4 \times 10^{-6}$ ,  $b = 1.615$ ,  $X_i/p = 400$ ; if  $400 \leq X/p \leq 725$  (3).

TABLE 6.—IONIZATION OF HE BY ACCELERATED ELECTRONS: VARIATION WITH PRESSURE, FIELD CONSTANT

$\alpha$  is a maximum when  $p_m = X/16$ ; compare with Table 7 where value for  $NV_i$  indicates a pressure less than half as great. Unit of  $X = 1$  volt/cm; of  $p = 1$  mm of Hg; of  $\alpha = 1$  per cm.

$X = 120$ (69)				$X = 50$ (66)			
$\alpha$	$p$	$\alpha/p$	$X/p$	$\alpha$	$p$	$\alpha/p$	$X/p$
3.05	19	0.160	6.3	1.37	10.5	0.130	4.75
3.46	10	0.346	12.0	1.22	10.0	0.122	5
3.57	6	0.595	20.0	1.56	3.13	0.498	16
3.37	4	0.842	30.0				

TABLE 7.—ENERGY ( $E_i$ ) EXPENDED BY ELECTRONS IN IONIZING A MOLECULE: VARIOUS GASES

$E_i = eV_i$ ;  $Np$  = number of collisions per unit length of path of electron = maximum value of  $\alpha$  for given  $p$ ;  $NV_i = X/p_m$ , where  $p_m$  is the pressure at which  $\alpha$  is a maximum for a given  $X$ . Unit of  $V_i = 1$  volt; of  $Np = 1$  per cm; of  $p = 1$  mm of Hg.

Gas	$V_i$	$N$	$NV_i$	Lit.
Air.....	25	14.6	365	(63)
	27.1	12.6	341	(51)
	10.21*			(3)
A.....	17.3	13.6	235	(63)
H <sub>2</sub> .....	26.0	5.0	130	(63)
	27.8	5.5	153	(51)
	9.66*			(3)
He.....	12.3	2.8	34.4†	(63)



TABLE 7.—(Continued)

Gas	$V_i$	$N$	$NV_i$	Lit.
He.—(Continued).....	14.5	2.4	34.8†	(63)
N <sub>2</sub> .....	27.6	12.4	342	(63)
	27.9	12.4	346	(51)
O <sub>2</sub> .....	23.9	11.2	268	(51)
H <sub>2</sub> O.....	22.4	12.9	289	(63)
HCl.....	16.5	22.2	366	(63)
CO <sub>2</sub> .....	23.3	20.0	466	(63)
	23.5	16.2	381	(51)
	6.21*			(3)

\* Observations at pressures &gt;1 cm Hg.

† This exceeds twice the value of  $X/p_m$  given in Table 6.TABLE 8.—IONIZATION OF AIR BY  $\alpha$ -PARTICLES<sup>a</sup> VARIATION WITH VELOCITY

No appreciable ionization is produced by an  $\alpha$ -particle unless  $v > 0.025c$  (53, 55). If, at a distance  $x$  from its source, an  $\alpha$ -particle of range  $R$ , in the gas considered, produces  $\beta dx$  pairs of ions in a length of path =  $dx$ , then, quite roughly,  $\beta = a/(R-x)^{1/2}$  and  $v/c = b(R-x)^{1/2}$  (22); for air,  $a = 4.50 \times 10^4 \text{ cm}^{-3/2}$  (23),  $b = 0.0342 \text{ cm}^{-1/2}$  (Vol. I, p. 362). For values of  $R$  and  $v_1$  (initial velocity), see Vol. I, p. 362, 363. For  $\alpha$ -particles from Ra-C' in air at 12°C and 1 atm.,  $\beta$  varies as follows (21):

$x$ .....	1	2	3	4	5	6	6.5 ±	7 ± cm
$\beta/1000$ .....	22.5	23	24	28	36	55	76	40 cm <sup>-1</sup>

The total number of ions produced is  $I = \int_0^R \beta dx = KR^{3/2}$ , where  $K = 1.50a$ ; for air,  $K = 6.76 \times 10^4 \text{ cm}^{-3/2}$  (22). Unit of  $I = 1000$ . Gas is air.

Source	$100v_1/c$	$I$	Source	$100v_1/c$	$I$
U <sub>I</sub> .....	4.56	133	Rd-Ac.....	5.59	187
Th.....	4.69	137	Ra-A.....	5.65	187
U <sub>II</sub> .....	4.79	143	Th-C.....	5.72	189
Io.....	4.85	146	Tn.....	5.74	195
Ra.....	5.00	152	Ac-C.....	5.89	205
Pa.....	5.10	160	Th-A.....	6.00	209
Ra-F*.....	5.23	167	An.....	6.00	211
Rd-Th.....	5.27	169	Ac-A.....	6.27	228
Rn.....	5.40	171	Ra-C'.....	6.41	237
Th-X.....	5.46	177	Th-C'.....	6.88	274
Ac-X.....	5.50	178			

\*  $I = 158$  (2).TABLE 9.—RELATIVE MOLECULAR AND TOTAL ( $I_r$ ) IONIZATION OF GASES BY  $\alpha$ -PARTICLES FROM RADIUM AND POLONIUM

$n_r \equiv n/n_a = C_r p T_a / p_a T$ ;  $n_a, p_a, T_a$  refer to air.  $v_1 = 0.0500c$ ; for ionization of air, see Table 8

Gas	Ra	Po	Gas	Ra	Po
	$C_r^*$	$I_r^*$		$C_r^*$	$I_r^*$
Air.....	1.00	1.00	N <sub>2</sub> O.....	1.53	1.02
A.....	1.24		NH <sub>3</sub> .....	0.81	0.90
Br.....	3.90		CO.....	1.00	1.02
H <sub>2</sub> .....	0.23	0.99	CO <sub>2</sub> .....	1.55	1.02
He.....	0.22		CCl <sub>4</sub> .....	5.30	1.32
Kr.....			CS <sub>2</sub> .....	2.99	1.38
N <sub>2</sub> .....	0.94†	0.96	C <sub>2</sub> N <sub>2</sub> .....	1.93	
Ne.....			CHCl <sub>3</sub> .....	4.08§	1.29
O <sub>2</sub> .....	1.14	1.13	CH <sub>3</sub> Br.....	2.75	1.32
Xe.....			CH <sub>3</sub> I.....	3.43§	1.33
HCl.....		1.29	CH <sub>4</sub> .....	1.06	1.18
HBr.....		1.29	CH <sub>4</sub> O.....	1.74	1.22
HI.....		1.29	C <sub>2</sub> H <sub>2</sub> .....	1.40	1.26
SO <sub>2</sub> .....	2.02	1.03	C <sub>2</sub> H <sub>4</sub> .....	1.65	1.22
NO.....	1.28		C <sub>2</sub> H <sub>4</sub> O  .....	2.14	1.05

Table 9.—(Continued)

Gas	Ra	Po	Gas	Ra	Po
	$C_r^*$	$I_r^*$		$C_r^*$	$I_r^*$
C <sub>2</sub> H <sub>5</sub> Cl.....	3.10	1.29	C <sub>4</sub> H <sub>10</sub>   .....	4.02	
C <sub>2</sub> H <sub>5</sub> I.....	4.00	1.28	C <sub>4</sub> H <sub>10</sub> O  .....	4.40	1.33
C <sub>2</sub> H <sub>6</sub> .....	2.02	1.30	C <sub>5</sub> H <sub>12</sub>   .....	4.85	1.35
C <sub>2</sub> H <sub>6</sub> O  .....	2.46	1.23	C <sub>6</sub> H <sub>6</sub>   .....	4.30	1.29
C <sub>2</sub> H <sub>8</sub> .....	3.05				

\* From (8, 9, 17, 37, 38, 39, 43, 46, 50, 61). † From (30, 62).

‡ Another observer (9) finds 0.24 for  $\alpha$  from Ra-C'.§ Strutt (60) finds 4.44 for CHCl<sub>3</sub>, and 3.51 for CH<sub>3</sub>I.|| C<sub>2</sub>H<sub>4</sub>O = acetaldehyde, C<sub>2</sub>H<sub>5</sub>O = ethyl alcohol, C<sub>4</sub>H<sub>10</sub> = butane, C<sub>4</sub>H<sub>10</sub>O = ethyl ether, C<sub>5</sub>H<sub>12</sub> = pentane, C<sub>6</sub>H<sub>6</sub> = benzene.TABLE 10.—IONIZATION OF GASES BY ACCELERATED POSITIVE RESIDUES: VARIATION WITH INTENSITY ( $X$ ) OF FIELD

The ionization is produced by the positive residues which result from ionizing the gas by impact of electrons. Unit of  $X = 1 \text{ volt/cm}$ ; of  $p = 1 \text{ mm of Hg}$ ; of  $\beta = 1 \text{ per cm}$ .

$X/p$	$100\beta/p$			
	A	H <sub>2</sub>	He	Air
610	24.5			
600	21.5			10.0
520	14.9			6.4
500	13.8			5.6
450	11.6			3.8
400	9.5			2.3
350	7.0	33.0		1.4
300	5.3	26.4		0.62
250	3.8	17.8		0.28
200	2.0	8.2	16.5	0.20
180	1.4	5.9	13.9	0.18
160	0.85	4.1	11.3	0.12
140	0.50	2.6	9.0	0.10
120	0.40	1.60	7.0	
100	0.30	1.03	5.4	
80	0.20	0.64	4.0	
50	0.10	0.20	2.0	
30			1.0	
Lit.	(25)	(64, 68)	(26)	(25, 63, 64, 68)

TABLE 11.—ATOMIC IONIZATION RELATIVE TO AIR

If  $C_r$  = coefficient of molecular ionization of the gaseous compound  $F_r G_r H_r$  relative to air, and  $E_r = E_i/E_{ia}$ , where  $E_{ia}$  = value of  $E_i$  for air, then, in many cases, quite approximately  $C_r = f c_f + g c_g + h c_h$  and  $E_r = f e_f + g e_g + h e_h$ , where  $c_f, c_g, c_h$  and  $e_f, e_g, e_h$  are numbers characteristic of the several constituent species of atoms. The  $c$ 's are called the atomic ionization relative to air. The atomic stopping power is  $ec$ .

Atom	$\alpha$ -particles; Ra		$\beta$ -rays; U-X	$\gamma$ -rays	$\gamma, \text{Zn}^*$
	$e$	$c$	$c$	$c$	$c$
Br.....	0.685	1.72	2.67	2.81	4.71
C.....	0.894	0.51	0.46	0.46	0.44
Cl.....	0.676	1.16	1.44	1.44	1.50
H.....	0.754	0.175	0.18	0.18	0.18
	1.14†	0.116†			
I.....	0.658	2.26	4.10	4.50	10.88
N.....	1.05	0.47	0.475	0.45	0.41
Ni.....				1.82	2.56
O.....	0.962	0.55	0.58	0.58	0.57
S.....	0.603	1.24	1.60	1.60	1.48
Lit.	(38)	(38)	(37)	(37)	(37)

\* Secondary rays from Zn. † Pure atomic H.



TABLE 12.—RELATIVE MOLECULAR IONIZATION OF GASES BY  $\gamma$ -RAYS AND X-RAYS

See also Table 13.  $n_r \equiv n/n_a = C_r p T_a / p_a T$ ;  $n_a$ ,  $p_a$ ,  $T_a$  refer to air.  $E_r = (E_i)_{\text{gas}} / (E_i)_{\text{methyl acetate}}$ .  $R_{\text{sec}}$  = relative amount of secondary radiation emitted by the gas. Soft X-rays are those stopped by 0.3 mm Pb; hard X-rays are those which pass through 0.3 mm Pb (45).

Gas	$\gamma$ -rays, $C_r$						X-rays				
	Primary			Secondary			$C_r$		$R_{\text{sec}}$	$E_r$	
	Ra	Ra	Ra	C	Pb	Zn	Hard	Soft		Hard	Soft
Air.....	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
H <sub>2</sub> .....	0.169	0.19	0.160	0.084	0.139	0.088	0.177*	0.105* 0.114†			
O <sub>2</sub> .....	1.17		1.16	1.18	1.07	1.11	0.18 1.17*	1.30* 1.39†	0.12		
SO <sub>2</sub> §.....	2.13		2.27	2.49		2.17	4.79* 2.3	11.05* 7.97	4.10		
H <sub>2</sub> S.....		1.23									
N <sub>2</sub> O.....			1.55			1.34		1.47	1.53		
NH <sub>3</sub> .....			0.90	0.92	0.914						
CO <sub>2</sub> §.....	1.53		1.58	1.58	1.55	1.53	1.49 1.33*	1.57 1.46* 1.60†			
CCl <sub>4</sub> .....	5.67	5.6	6.33	6.00	6.16	6.35	1.33* 71.0	1.54* 67.3 45.3†	8.6	0.7	0.89
CS <sub>2</sub> .....			3.66	3.43	3.31	3.40					
CHCl <sub>3</sub> .....	4.88	4.8	4.93	5.08		5.20		31.9†			
CH <sub>3</sub> Br.....			3.81	6.47	5.83	6.15		71.0	215		
CH <sub>3</sub> I.....	4.80	5.2	5.37	15.19	10.36	12.07	125	145 72†	41.5	1.0	0.52
C <sub>2</sub> N <sub>2</sub> .....	1.71										
C <sub>2</sub> H <sub>2</sub> .....				1.24		1.20					
C <sub>2</sub> H <sub>4</sub> O.....			2.17			2.16					
C <sub>2</sub> H <sub>6</sub> Br.....			4.63	6.30		6.05	118	72	217	0.7	0.86
C <sub>2</sub> H <sub>6</sub> Cl.....			3.19			3.39	17.3	18.0	3.2	1.00	0.61
C <sub>2</sub> H <sub>6</sub> I.....			6.47	15.60		12.46					
C <sub>3</sub> H <sub>8</sub> O <sub>2</sub> ¶.....							3.90	4.95	2.72	1.00	1.00
C <sub>4</sub> H <sub>10</sub> O¶.....			4.29	4.35	4.34	4.29					
C <sub>5</sub> H <sub>12</sub> ¶.....			4.53		4.17	4.36					
Hg(CH <sub>3</sub> ) <sub>2</sub> .....								425			0.69
Ni(CO) <sub>4</sub> §.....			5.98			6.60	97	89	8.1	1.1	0.57
Lit.....	(60)	(17)	(8)	(8)	(8)	(8)	All (12, 13) except as indicated.				

\* (45). † (60). ‡ (48). || (17). § See also Table 13. ¶ C<sub>3</sub>H<sub>8</sub>O<sub>2</sub> = methyl acetate, C<sub>4</sub>H<sub>10</sub>O = ethyl ether, C<sub>5</sub>H<sub>12</sub> = pentane.

TABLE 13.—RELATIVE MOLECULAR AND TOTAL ( $I_r$ ) IONIZATION OF GASES BY SECONDARY X-RAYS

See also Table 12.  $n_r \equiv n/n_a = C_r p T_a / p_a T$ ;  $n_a$ ,  $p_a$ ,  $T_a$  refer to air. Unit of  $p = 1$  mm of Hg

Gas	CO <sub>2</sub>		SO <sub>2</sub>		SeH <sub>2</sub>
	$C_r$	$I_r$	$C_r$	$I_r$	
Ag.....					231
As.....	1.510	0.91	11.73	1.22	
Cu.....	1.552	0.89	11.84	1.08	29.2
Fe.....	1.581	0.90	11.34	1.07	30.3
I.....					286
Mo.....	1.541	0.92	11.45	1.00	190
Ni.....	1.546	0.88	11.57	1.25	
Se.....	1.533	0.86	11.76	1.11	30.6
Sn.....					250
Sr.....	1.527	0.94	11.81	1.04	122
Zn.....	1.538	0.91	11.52	1.18	
Lit.....	(49)	(49)	(49)	(49)	(1)

TABLE 14.—ENERGY ( $E_i$ ) EXPENDED IN IONIZING GASES

For X-rays, Kulenkampff (41) finds  $E_i = (5.56 \pm 0.79) \times 10^{-11}$  erg per ion-pair and independent of wave-length ( $\lambda$ ) if  $0.56 < \lambda < 2 \text{ \AA}$ . At shorter wave-lengths others find  $E_i = ae^{-b\lambda}$ ; for air  $a = 2.2 \times 10^{-10}$  erg per ion-pair,  $b = 5.08 \text{ \AA}^{-1}$ . In the table,  $E_i$  = observed value from which  $V_i$  is computed by relation  $E_i = eV_i$ . Unit of  $\lambda = 1 \text{ \AA}$ ; of  $E_i = 10^{-11}$  erg per ion-pair; of  $V_i = 1$  volt.

(1) X-rays; air

$\lambda$	$E_i$	$V_i$	Lit.	$\lambda$	$E_i$	$V_i$	Lit.
0.56	1.25	7.86	(7)	0.275	5.37*	33.7	(29, 40)
0.397	2.97*	18.6	(29, 40)	0.205	7.57*	47.5	(29, 40)
0.333	3.54*	22.2	(29, 40)	0.166	9.57*	60.1	(29, 40)
0.325	4.33	27.2	(7)				

\* Published in arbitrary units and here reduced to basis of others by dividing by the empirical factor  $3.50 \times 10^{-11}$ .



TABLE 14.—(Continued)  
(2)  $\alpha$ -rays from Po (30)

Gas	$E_i$	$V_i$	Gas	$E_i$	$V_i$
A	3.8	24	N <sub>2</sub>	5.25	33
H <sub>2</sub>	4.9	31	Ne	4.12	25.9
He	4.17	26.2	O <sub>2</sub>	4.86	30.5
Kr	3.43	21.5	Xe	3.12	19.6

TABLE 15.—IONIZATION OF GASES MIXED WITH VAPOR OF P (59)

The gas is in equilibrium with a liquid containing P. For column "A" the liquid is almond oil; for "W" it is H<sub>2</sub>O. See also (28, 31, 47, 58).

Relative ionizations

Gas	A*	W*	Gas	A*	W*
Air	1.0	1.0	CO <sub>2</sub>	59.6	28.7
H <sub>2</sub>	48.2	15.3	N <sub>2</sub> O		22.1
O <sub>2</sub>	5.5	2.9			

\* For air, the ionization over W is 2.16 times that over A; this ratio probably depends upon the relative amounts of P and upon its state of dispersion in the two liquids.

## LITERATURE

(For a key to the periodicals see end of volume)

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ELECTRICAL RESISTANCE OF ELEMENTARY SUBSTANCES AT TEMPERATURES BELOW  $-80^{\circ}\text{C}^*$ 

H. KAMERLINGH ONNES AND W. TUYN

## CONTENTS

## MATIÈRES

## INHALTSVERZEICHNIS

## INDICE

## PAGE

Resistance of pure elementary substances at various temperatures below  $-80^{\circ}\text{C}$ .

Résistance des substances élémentaires pures à des températures variées inférieures à  $-80^{\circ}\text{C}$ .

Widerstand elementarer reiner Stoffe bei verschiedenen Temperaturen unterhalb  $-80^{\circ}\text{C}$ .

Resistenza di elementi puri a varie temperature al di sotto di  $-80^{\circ}\text{C}$ ..... 125

Resistance of three platinum wires between  $-80$  and  $-270^{\circ}\text{C}$ .

Résistance de trois fils de platine entre  $-80$  et  $-270^{\circ}\text{C}$ .

Widerstand von drei Platin-drähten zwischen  $-80$  und  $-270^{\circ}\text{C}$ .

Resistenza di tre fili di platino fra  $-80$  e  $-270^{\circ}\text{C}$ ..... 130

Effect of impurities, heat treatment, tension, compression, etc.

Effet des impuretés, traitement thermique, tension, compression, etc.

Einfluss von Verunreinigungen, Wärmebehandlung, Dehnung, Druck, u.s.w.

Effetto delle impurezze, trattamento termico, tensione, compressione, ecc..... 131

(For symbols which are not here defined, see Vol. I, p. 16.)

(Pour les symboles qui ne sont pas expliqués ici, voir Vol. I, p. 16.)

(Zeichen, welche nicht hier definiert sind, siehe Bd I, S. 16.)

(Per i simboli che non sono qui definiti, vedi Vol. I, p. 16.)

As it is impracticable to determine the volume resistivity at very low temperatures, merely the ratio of the resistance of a given specimen at a given temperature to the resistance of the same specimen at  $0^{\circ}\text{C}$  is given; except that in a few cases the actual resistance of the specimen at each of a series of low temperatures is given, instead of its ratio. Extremely low temperatures are occasionally expressed in terms of the pressure of saturated helium vapor at the same temperatures; this is especially convenient for those cases in which a small change in temperature is accompanied by a great change in the resistance.

If the resistances of a number of impure specimens (1, 2, . . .  $n$  . . .) of the same metal, all of the same dimensions at  $0^{\circ}\text{C}$ , are measured at a series of temperatures, and if the observations are plotted in rectangular coordinates ( $R_{nt}$  vs.  $t$ ) and are connected by smooth curves, a curve for every specimen, then it is found (133) that these curves differ, roughly, solely by a displacement

parallel to the axis of  $R$ , and that the purer the specimen the more nearly does its resistance approach zero as  $t$  approaches the absolute zero. The composite curve obtained by displacing these curves parallel to the axis of  $R$  until they all pass through the point  $R = 0$  at the absolute zero is called the curve corresponding to a specimen of the metal of "ideal" purity and condition, and of the same dimensions at  $0^{\circ}\text{C}$  as the actual specimens. If the resistances corresponding to the points upon this "ideal" curve be denoted by  $R_{it}$  and if  $p_n x_n$  is the displacement which makes the curve corresponding to specimen  $n$  coincide with the "ideal" curve, then

$$R_{x_n t} = R_{it} + p_n x_n$$

If  $x_n$  is the percentage of admixed impurity,  $p_n$  has a large value which, over a certain temperature range, is independent of  $t$ , but depends upon the nature and the amount of the impurity, and upon the state, or condition, of the specimen (133).

Expressions which are independent of the actual dimensions of the specimens may be obtained by dividing each equation by the

\* Published in somewhat greater detail in (141).



resistance of the specimen at  $0^{\circ}\text{C}$ . Doing this, writing  $p_n x_n$  for  $p_n x_n / R_{x_n 0}$ , and remembering that  $R_{i0} / R_{x_n 0} = 1 - p_n x_n$  we find (17, 18)

$$\frac{R_{x_n t}}{R_{x_n 0}} = \frac{R_{i0}}{R_{x_n 0}} (1 - p_n x_n) + p_n x_n$$

and

$$\Delta\left(\frac{R}{R_0}\right) = \frac{R_{x_2 t}}{R_{x_2 0}} - \frac{R_{x_1 t}}{R_{x_1 0}} = \frac{p_2 x_2 - p_1 x_1}{1 - p_1 x_1} \left(1 - \frac{R_{x_1 t}}{R_{x_1 0}}\right) = a \left(1 - \frac{R_{x_1 t}}{R_{x_1 0}}\right)$$

where  $a$  is independent of  $t$ . This is Nernst's rule (106, 108). The exactness with which it represents the observations depends upon the value of  $a$ ; between 0 and  $-200^{\circ}\text{C}$  departures may amount to those corresponding to errors of 0.05 to  $0.20^{\circ}\text{C}$  in the temperature (86, 146, 147). For temperatures above  $-208^{\circ}\text{C}$  for Au and above  $-216^{\circ}\text{C}$  for Pt, a closer approximation, to at least  $0.02^{\circ}\text{C}$  (17, 18), is given (62, 63, 64, 65) by

$$\Delta\left(\frac{R}{R_0}\right) = M \left\{ \frac{R_{x_2 t}}{R_{x_2 0}} - 1 \right\} + N \left\{ \frac{R_{x_2 t}}{R_{x_2 0}} - 1 \right\}^2$$

Various expressions, several of which are based upon the quantum theory, have been proposed for the variation of the resistance with the temperature. Only one or two examples can be given here. For monatomic metals at low temperatures, Grüneisen (43, 44, 45) finds that quite closely  $R \propto T c_p$ , or  $R \propto T \frac{c_p}{c_v} f(T/\theta)$ , and at intermediate temperatures  $R \propto T \{1 + a_1 T + a_2 T^2\} f(T/\theta)$  (44);  $T$ ,  $c_p$ , and  $c_v$  have their usual significance (Vol. I, p. 16), and  $\theta$  and  $\theta_r$  are temperatures characteristic of the substance. Other examples will be found in (12, 60, 61, 96, 106, 112, 163); see also (141).

If  $M$  is the molecular weight of a substance, the volume of  $M$  grams of the substance may be called its gram-molecular volume, and the length of one edge and the area of one face of a cube having a volume equal to its gram-molecular volume may be called its gram-molecular length and its gram-molecular area, respectively. Likewise, the resistance between opposite faces of a cube containing one gram-molecular volume of the substance may be called its gram-molecular resistivity; and, if uniformly distributed over the area, the amount of current which passes normally through a plane section of one gram-molecular area may be called the gram-molecular surface density of the current. Gram-atomic quantities are defined in a similar manner.

For all elements having the same constellation of outer electrons, the gram-atomic conductivity seems to be the same at those respective temperatures for which  $T/\theta_r$  has a given value (5, 38, 40, 151, 162), or as Epstein claims, at those which are the same fraction of the absolute melting points (36). Cassel (16) claims that for such elements a more nearly correct statement is: The gram-atomic surface density of the current for a gradient of 1 volt/cm (which he calls the atomic current strength) is the same at those respective temperatures for which  $T/\theta_r$  has a given value.

At temperatures below  $-192^{\circ}\text{C}$ , the order of the curves of  $R/R_0$  vs.  $t$  agrees with that of the values of  $h\nu/k$ , where  $\nu$  is a frequency calculated from the specific heats of the elements (146, 147).

For complete bibliography, arranged by elements, see p. 134.

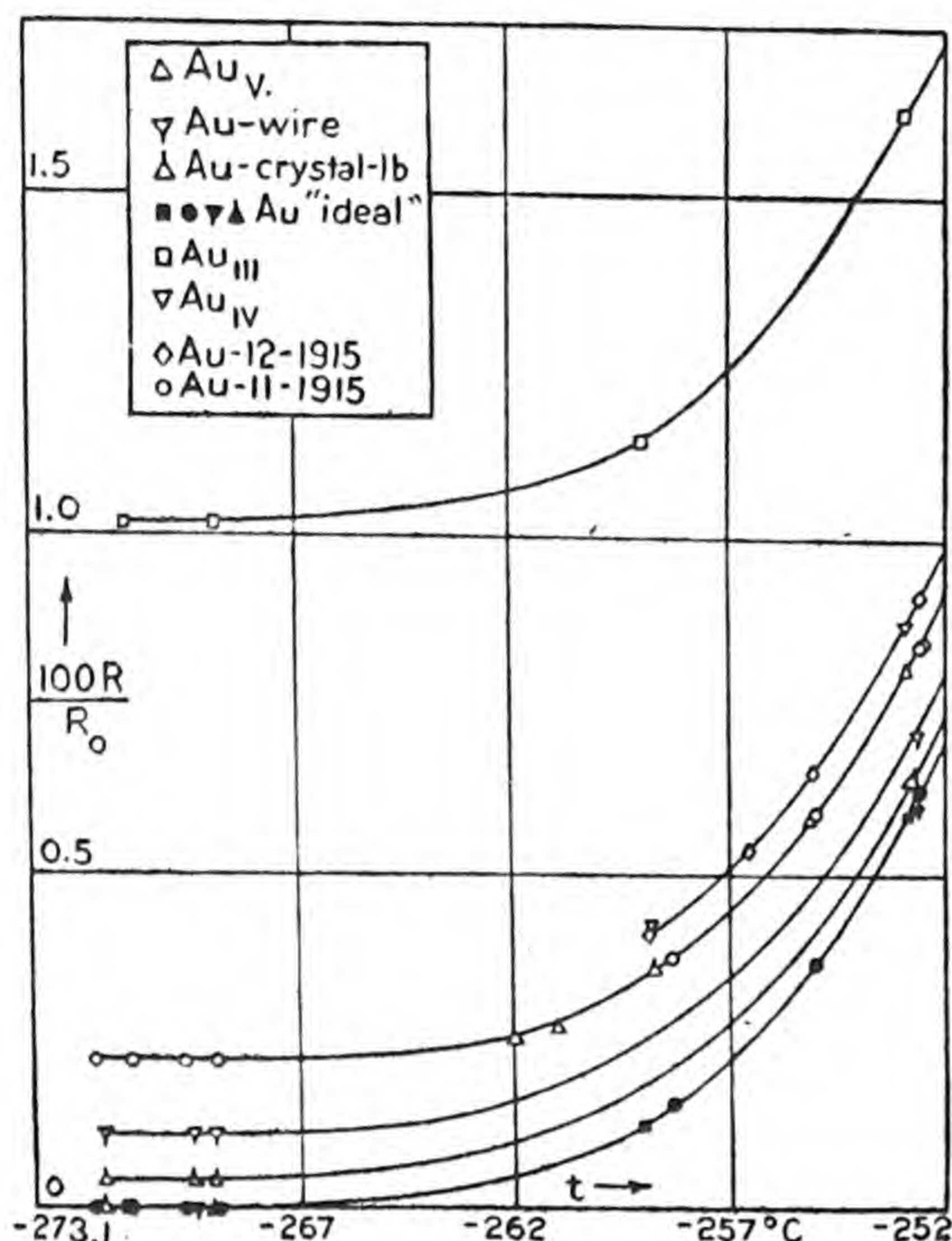
TABLE 1.—ELECTRICAL RESISTANCE OF ELEMENTARY SUBSTANCES AT TEMPERATURES BELOW  $-80^{\circ}\text{C}$

$R$ ,  $R_0$  = resistance (not resistivity) of the specimen at  $t$ ,  $^{\circ}\text{C}$ , at  $0^{\circ}\text{C}$ .  $d$  = diameter of wire,  $i$  = current. Italicized numbers are actual results of observations, others are obtained by interpolation.  $t$  = centigrade temperature,  $^{\circ}\text{C}$ ; every  $t$  is negative.

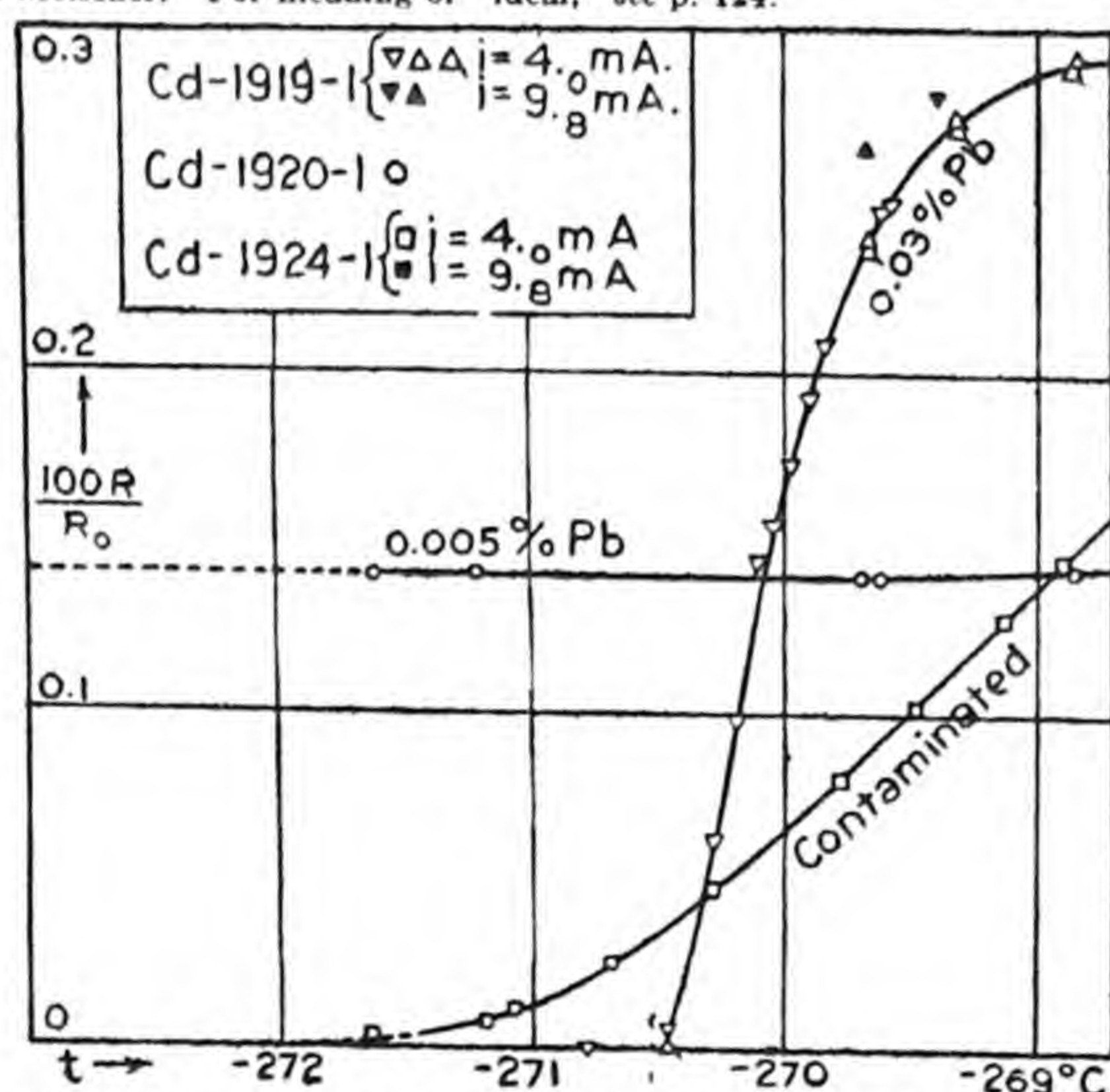
For footnotes to table, see p. 130.

Ag (22, 133)		Au.—(Cont'd)		Au.—(Cont'd)	
$-t$	$100R/R_0$	$-t$	$100R/R_0$	$-t$	$100R/R_0$
80	67.8	170	32.460	248	1.558
100	59.6	172	31.635	249	1.376
103.81	58.087	174	30.807	250	1.209
120	51.4	176	29.977	251	1.056
139.87	43.282	178	29.145	252	0.918
140	43.2	180	28.311	252.57	0.845
160	34.8	182	27.475	253	0.794
180	26.3	183.95	26.660	254	0.685
183.57	24.679	184	26.639	255	0.591
195.17	19.703	186	25.800	255.01	0.594
200	17.6	188	24.958	256	0.512
204.67	15.528	190	24.114	257	0.447
220	9.2	192	23.268	258	0.394
240	2.6	194	22.420	258.35	0.379
252.92	0.8913	195.88	21.622	259	0.351
259.22	0.6942	196	21.571	260	0.317
Second sample (135)		198	20.720	261	0.290
270.3	No*†	200	19.867	262	0.269
		202	19.013	263	0.253
		204	18.157	264	0.242
		205.31	17.596	265	0.234
		206	17.300	266	0.229
		208	16.442	267	0.226
		208.18	16.365	268	0.224
		210	15.584	268.88	0.223
		212	14.728	269	0.223
		214	13.872	269.57	0.223
		216	13.017	270	0.223
		216.26	12.906	270.84	0.223
		218	12.163	271	0.223
		220	11.310	271.61	0.223
		221	10.884	Single crystal (104, 105)	
		222	10.459		
		222.78	10.130	191.37	23.20
		223	10.035	193.14	22.52
		224	9.613	200	19.5
		225	9.194	220	10.9
		226	8.779	240	3.3
		227	8.368	252.69	0.642
		228	7.962	260	0.10
		228.73	7.680	268.89	0.039
		229	7.561	269.38	0.038
		230	7.165	271.48	0.039
		231	6.775	Bi (22, 133)	
		232	6.391		
		233	6.014	80	71.3
		233.62	5.804	100	64.8
		234	5.644	103.71	63.649
		235	5.282	120	58.6
		236	4.928	139.88	52.865
		236.80	4.667	140	52.8
		237	4.583	160	47.3
		238	4.247	164.05	46.246
		239	3.921	180	42.1
		240	3.605	182.73	41.435
		240.25	3.538	195.17	38.478
		241	3.300	200	37.2
		242	3.007	204.68	36.064
		243	2.727	216.01	33.014
		243.68	2.553	220	32.0
		244	2.461	240	26.7
		245	2.210	253.01	22.329
		245.80	2.039	255.34	21.388
		246	1.974	258.86	19.574
		24	1.757		



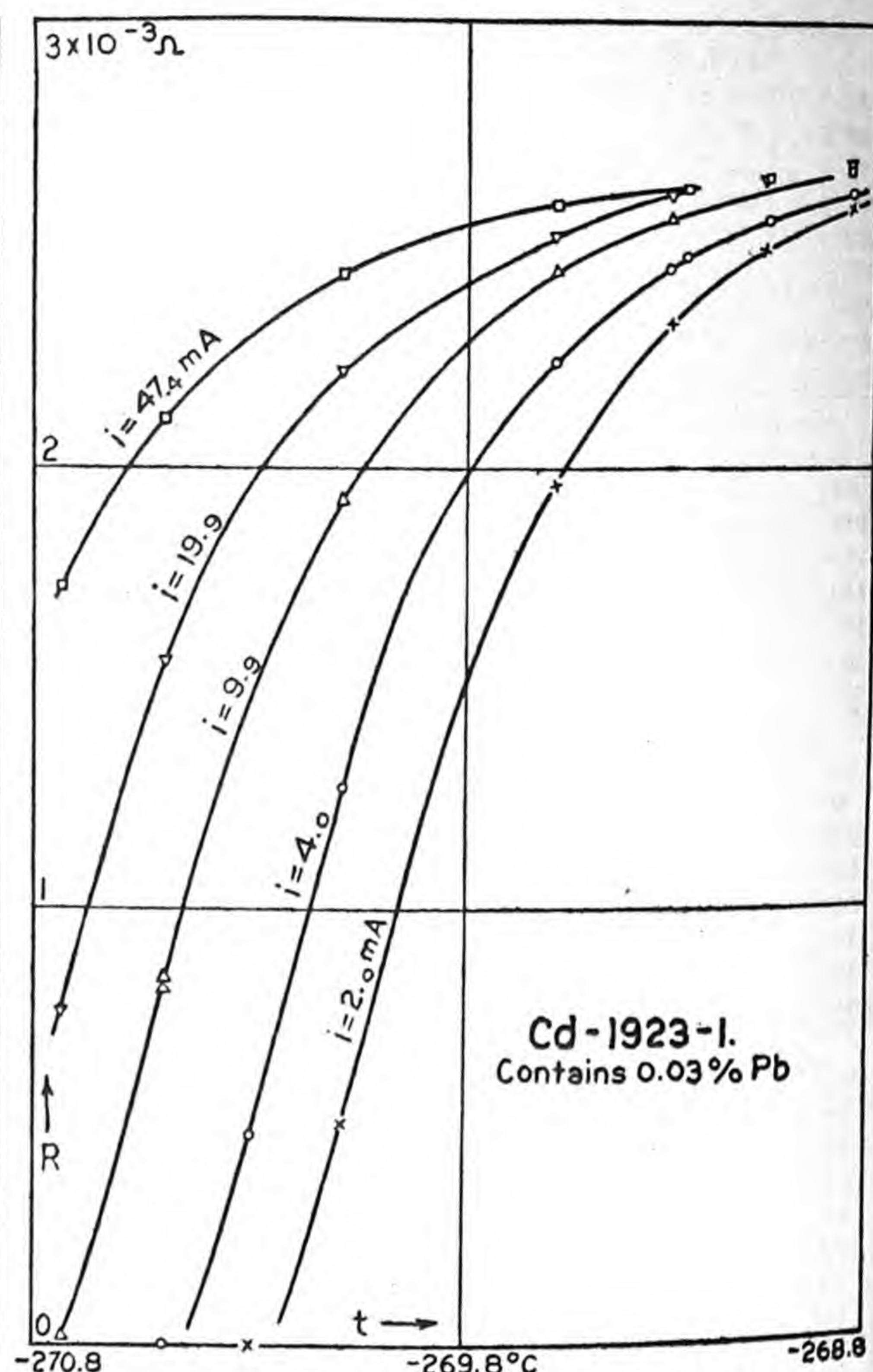
FIG. 1.—Gold: Variation of  $R$  with temperature.

Au<sub>III</sub> (22, 116, 133), Au<sub>IV</sub> (22, 133), Au-12-1915 (17, 18), Au-11-1915 (16, 17, 18), Au<sub>v</sub> (22, 133), Au-wire (104), Au-crystal-1b (104, 105). The last two are from Meissner. For meaning of "ideal," see p. 124.

FIG. 2.—Cadmium: Variation of  $R$  with temperature ( $t$ ) and current ( $i$ ) (157, 160).

Wires extruded from Kahlbaum Cd; "1919" is from old material; "1924" was drawn through a die contaminated with Pb.

Bi.—(Cont'd)		Bi.—(Cont'd)		Bi.—(Cont'd)	
Second sample (135)	$-t$	$100R/R_0$	$-t$	$100R/R_0$	$-t$
268.84	No*	157.1	47.2	161.1	60.2
Single crystal (11)§	80	75.4	C		
180	69.3	96.1	Graphite (135, 145)		
92.1	66.3	100	78	92	
100	64.4	120	80	92	
120	59.4	124.1	120	86	
128.1	57.1	140	160	77	
140	53.5	160	179	71	
			200	61	

FIG. 3.—Cadmium: Variation of  $R$  with current ( $i$ ) (157, 160). From old material.

C.—(Cont'd)		Cd.—(Cont'd)		Cd.—(Cont'd)	
$-t$	$100R/R_0$	$-t$	$100R/R_0$	$-t$	$100R/R_0$
240	28.5	192.08	25.125	140	44.7
253.1	15.8	200	21.96	143.15	43.5
258.9	9.5	200.03	21.967	160	37.1
Carbon (22, 134)		207.10	19.158	180	29.4
80	114	216.32	15.475	183.4	28.3
102.99	115.89	220	14.0	188.1	26.2
120	117	240	6.2	188.9	26.0
160	119	252.58	2.267	189.8	25.6
200	120	255.03	1.666	191.1	25.0
240	122	256.56	1.331	200	21.4
252.93	122.52	258.87	0.907	220	13.5
255.13	123.95	260	0.725	240	5.9
Cd (157, 159, 160);		268.87	0.143	252.67	1.87
cf. (78, 83); see		269.63	0.141	252.72	1.86
Figs. 2, 3		269.70	0.141	78.2	69.4
78.3	69.08	271.22	0.140	80	68.5
80	68.6	271.69	0.140	100	60.7
100	60.5	Single-crystal§		120	53.0
120	52.7	(47, 48)		140	45.3
140	45.1	178.2	69.3	143.15	43.9
160	37.5	80	68.5	160	37.6
180	29.85	100	60.3	180	30.0
182.68	28.820	120	52.4	183.4	29.1



## Cd.—(Cont'd)

$-t$	$100R/R_0$
184.8	28.2
188.1	27.0
190.1	26.3
191.1	25.8
200	22.2
220	14.3
240	6.8
252.67	2.204
252.72	2.207

Co (80); cf.  
(146, 147)

80	57.4
100	48.2
120	40.0
140	32.3
160	24.8
180	17.4
192	13.5

## Cs (57)

75	65.9
80	63.9
100	56.0
120	48.6
140	41.9
160	35.6
180	29.5
190	26.4

## Cu (55, 69)

76	65.739
80	64.9
100	55.7
120	46.5
140	37.3
160	28.6
180	20.1
183	18.868
200	11.7
220	4.7
240	1.2
252.8	0.6291

## Second sample (137)

Single crystals<sup>¶</sup>  
(157, 159, 160)

180	19.5
184.53	17.49
192.04	14.40
199.98	11.03
200	11.0
206.94	8.40
218.09	4.69
220	4.05
240	0.74
252.57	0.154
255.07	0.129
256.63	0.109
258.77	0.097

## Fe (78, 79, 83)

78.1	57.865
80	56.9
100	47.3
120	38.1
140	29.2
160	20.7

## Fe.—(Cont'd)

$-t$	$100R/R_0$
180	13.1
192.7	8.48
200	6.2
220	2.7
240	1.45
253	1.13

## Ga (157, 160)

271.5	No*††
-------	-------

## Ge (8)

79	82.75
80	82.3
95	80.3
100	80.3
108	79.3
112	80.9
113	79.7
117	80.4
120	80.7
140	83.8
155	86.1
160	89.2
168	91.8
177	96.9
180	96.5
183	98.8
185	99.3
193	106.8

Second sample  
(157, 160)

270.74	No*††
--------	-------

Hg†† (137); for  
superconductivity,  
see (56, 113, 114,  
115, 117, 152); see  
Figs. 4 and 5

80	67.1
88.17	63.72
100	58.8
107.29	55.86
118.87	51.31
120	50.9
131.26	46.60
140	43.4
140.37	43.29
150.28	39.82
156.57	37.66
160	36.4
180	29.5
182.96	28.51
192.17	25.37
200	22.8
220	16.0
240	9.1
252.70	4.904
255.20	4.072
257.31	3.354
258.52	2.946
260	0.245
268.76	0.206
268.80	0.200
268.86	0.183
268.94	0.176

## Hg.—(Cont'd)

## Second sample

Figs. 4, 5 | Yes\*

In (157, 158, 159);

see Figs. 6, 7

$-t$	$100R/R_0$
182.79	28.759
194.06	24.922
200	22.88
202.07	22.202
209.98	19.527
218.30	16.717
220	16.15
240	14.5
252.65	5.739
254.95	5.173
256.61	4.796
258.89	4.317
260	4.1
268.87	3.894
269.49	3.392
269.61	3.387
269.67	3.387

## V. p. He||| ¶¶

309.8	3.387
308.7	3.385
307.4	2.02
306.9	0.67
306.0	Yes*

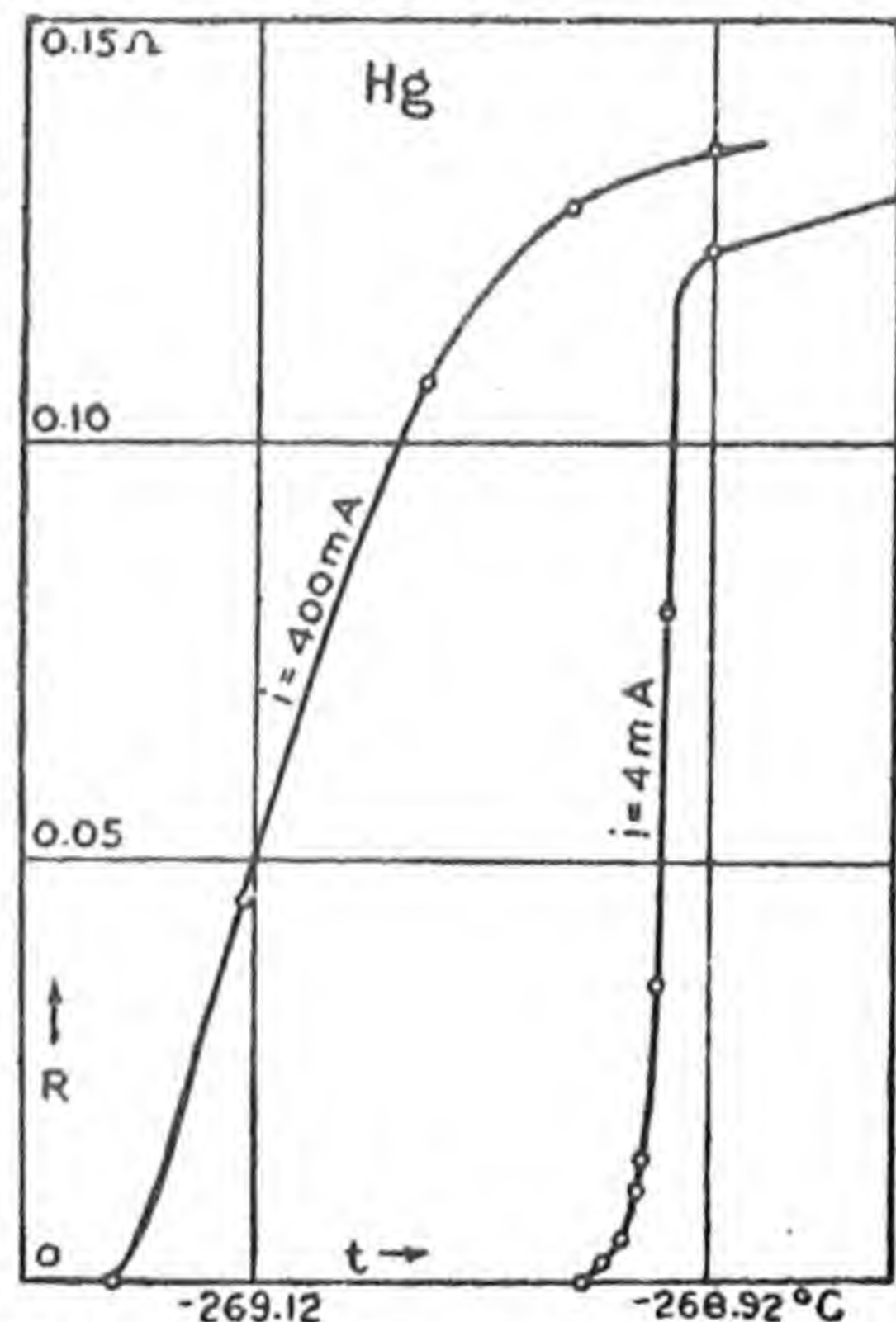
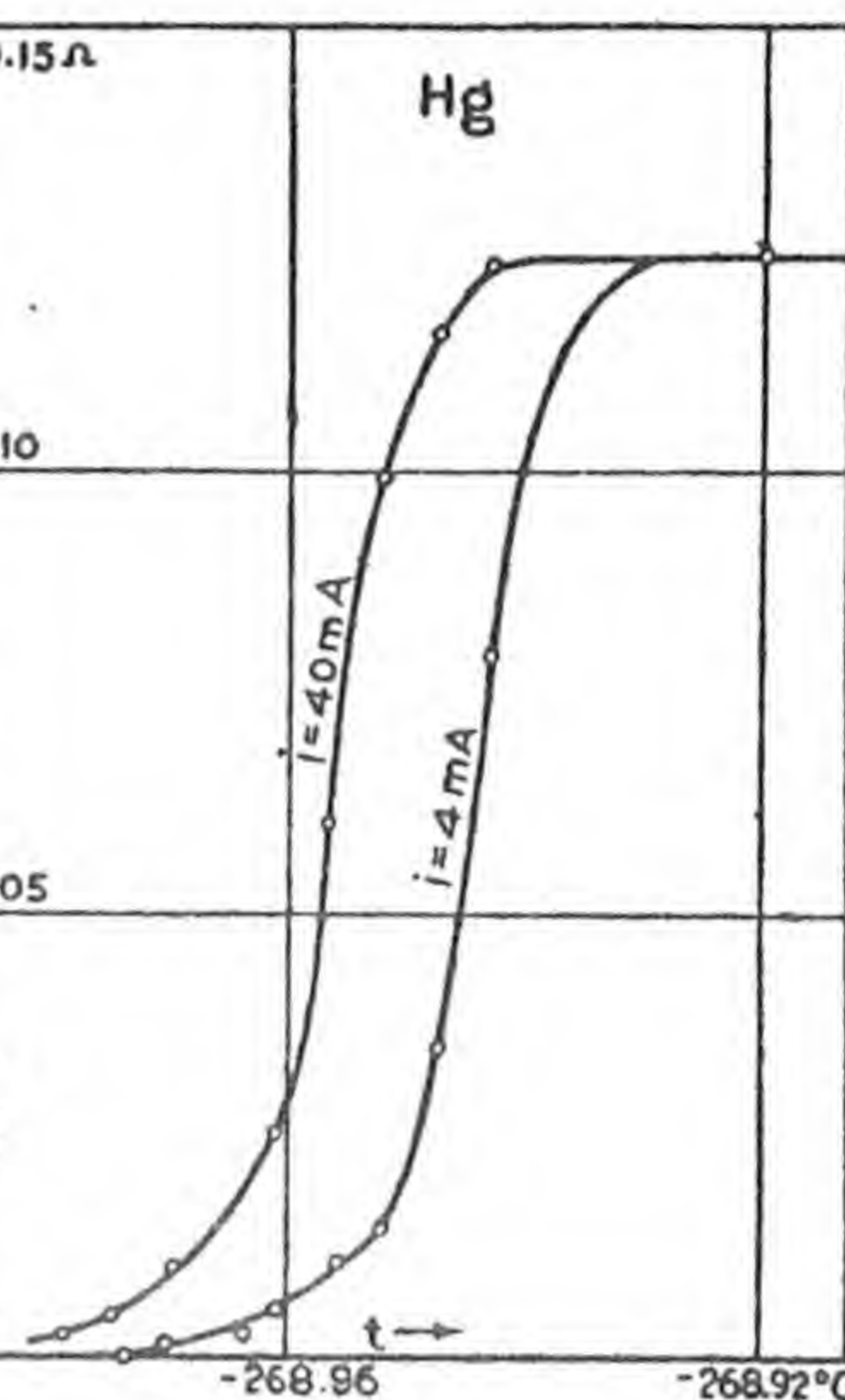
 $d = 0.17\text{mm}; i = 4.0\text{mA}$ 

## Ir (78, 83)

78.4	69.22
80	68.6
100	60.6
120	52.5
140	44.4
160	36.0
180	27.5
191.9	22.57

## K (164, 165)

80	65.8
100	57.7
102.22	56.88
120	50.1
140	42.7
160	35.6
164.37	33.87
180	28.4
182.6	27.47
182.96	27.19
200	21.1
200.2	21.11
200.96	20.70
216.32	15.14
216.75	15.14
220	13.8
240	6.6
252.54	2.708
252.74	2.703
254.69	2.213
255.97	1.943
256.77	1.787
258.89	1.434

Figs. 4, 5.—Mercury: Variation of  $R$  with current ( $i$ ) (117).

## K.—(Cont'd)

$-t$	$100R/R_0$
258.96	1.429
260	1.29
268.9	0.702
269.6	0.697
270.9	0.695

## Li (103); cf. (52, 54)

80	62.3
100	53.0
120	44.0
140	35.2
160	26.6
180	18.3
182.20	17.37
192.95	13.06
200	10.4
220	4.4
240	1.2
252.67	0.73

## Li.—(Cont'd)

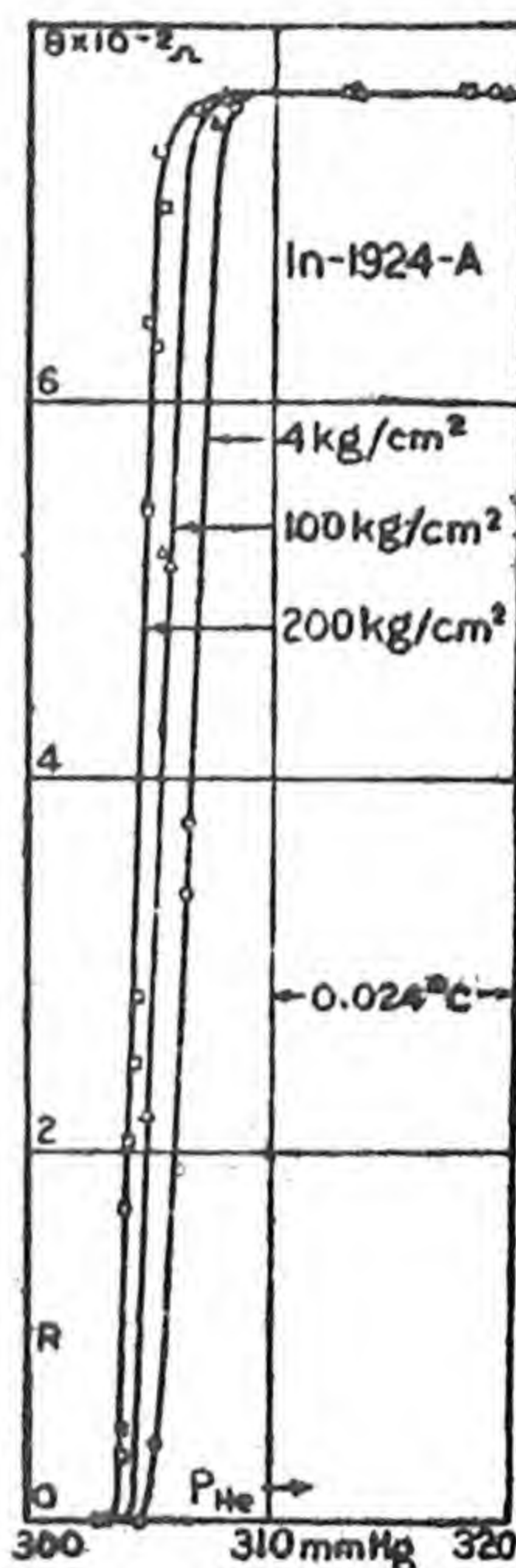
$-t$	$100R/R_0$
271.43	3.45

## Mg (28)

78.3	68.2
80	67.4
100	59.0
120	50.5
140	41.9
160	33.2
180	24.4
182.95	23.0

## Mo (78, 83)

78.2	66.60
80	65.9
100	57.4
120	48.9
140	40.5
160	32.2
180	24.2
192.5	19.11

Fig. 6.—Indium: Variation of  $R$  with pressure and temperature (152, 154).

## Na (165)

$-t$	$100R/R_0$
80	66.0
100	57.8
102.22	56.89
120	49.7
140	41.7
160	33.7
164.37	31.94
180	25.7
182.95	24.40
200	17.6
200.96	17.04
216.32	10.89
220	9.4
240	3.1
260	0.45
268.9	0.381
269.6	0.382
270.9	0.382
271.6	0.382



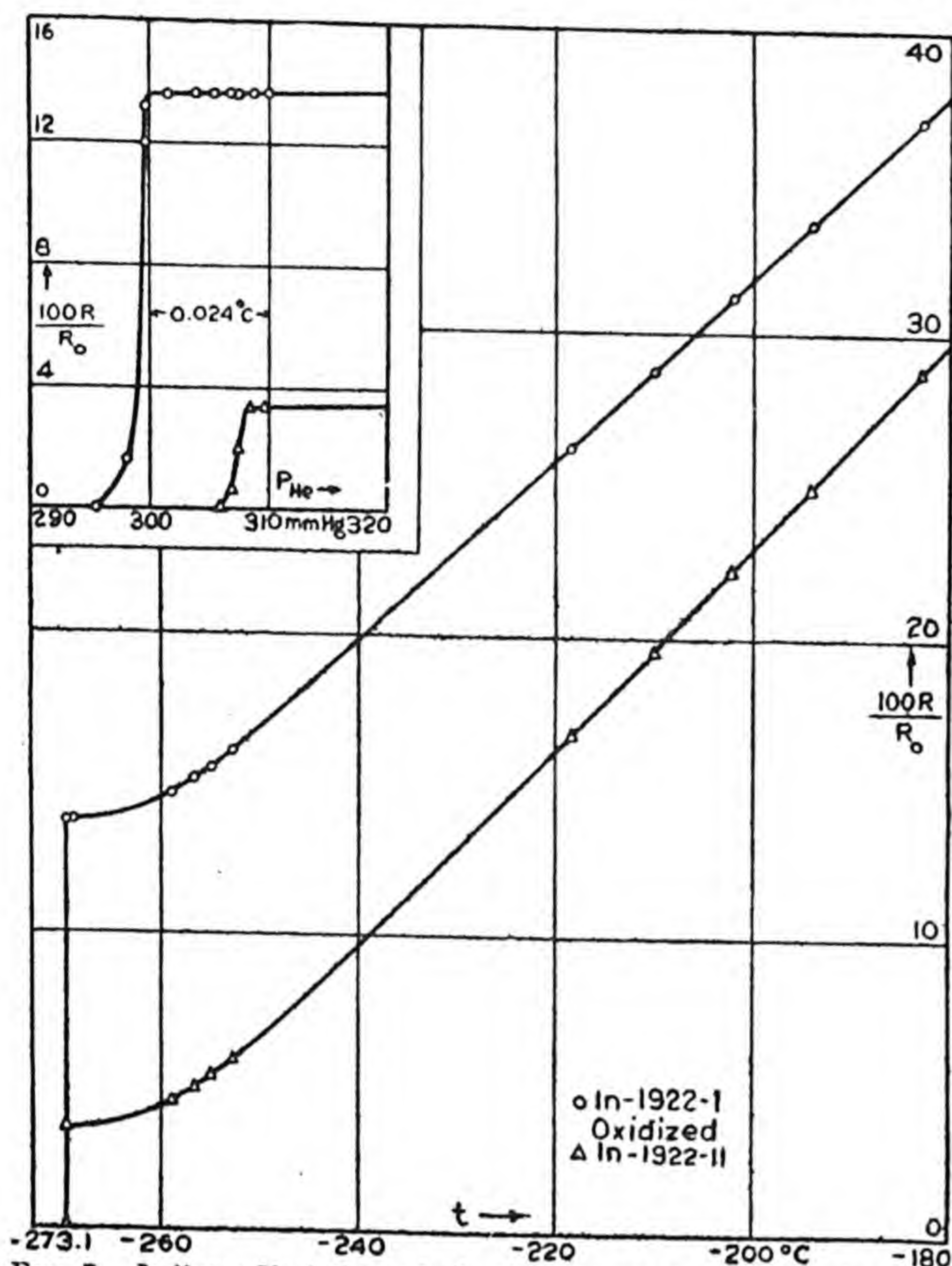


Fig. 7.—Indium: Variation of  $R$  with temperature, and effect of oxidation (157, 158, 159).

Ni (26, 40)		Pb.—(Cont'd)		Pd (78, 79, 83)	
$-t$	$100R/R_0$	$-t$	$100R/R_0$	$-t$	$100R/R_0$
78.3	61.3	190	26.94	78.1	68.51
80	60.5	192.04	26.171	80	67.7
100	51.8	199.98	23.208	100	59.1
120	43.7	200	23.20	120	50.4
140	36.1	205	21.31	140	41.8
160	28.7	206.935	20.600	160	33.0
180	21.7	210	19.42	180	24.2
182.95	20.8	215	17.55	182.7	18.44
200	15.6	218.09	16.384	200	15.2
220	11.2	220	15.68	220	7.5
240	8.9	225	13.58	240	2.7
252.76	8.55	230	11.52	253	0.93
Second sample (135)		235	9.50	Pt; see Table 2	
270.3	No*†	240	7.54	Rb (57)	
Pb† (140, 157, 159, 160); cf. (83)		245	5.65	78	54.8
80	68.31	250	3.86	80	53.5
90	64.46	252.57	3.014	100	46.3
100	60.64	255	2.21	120	39.9
110	56.82	255.07	2.188	140	34.2
120	53.03	256.63	1.715	160	28.8
130	49.24	258.77	1.135	180	23.8
140	45.48	260	0.85	190	21.6
150	41.73	262.7	0.40	Rh (78, 83)	
160	38.00	264.4	0.18	78.4	65.80
170	34.30	265	0.14	80	65.1
180	30.61	265.5	0.11	100	56.4
184.53	28.947	265.83	0.10	120	47.7
		265.83+	Yes*	140	39.0

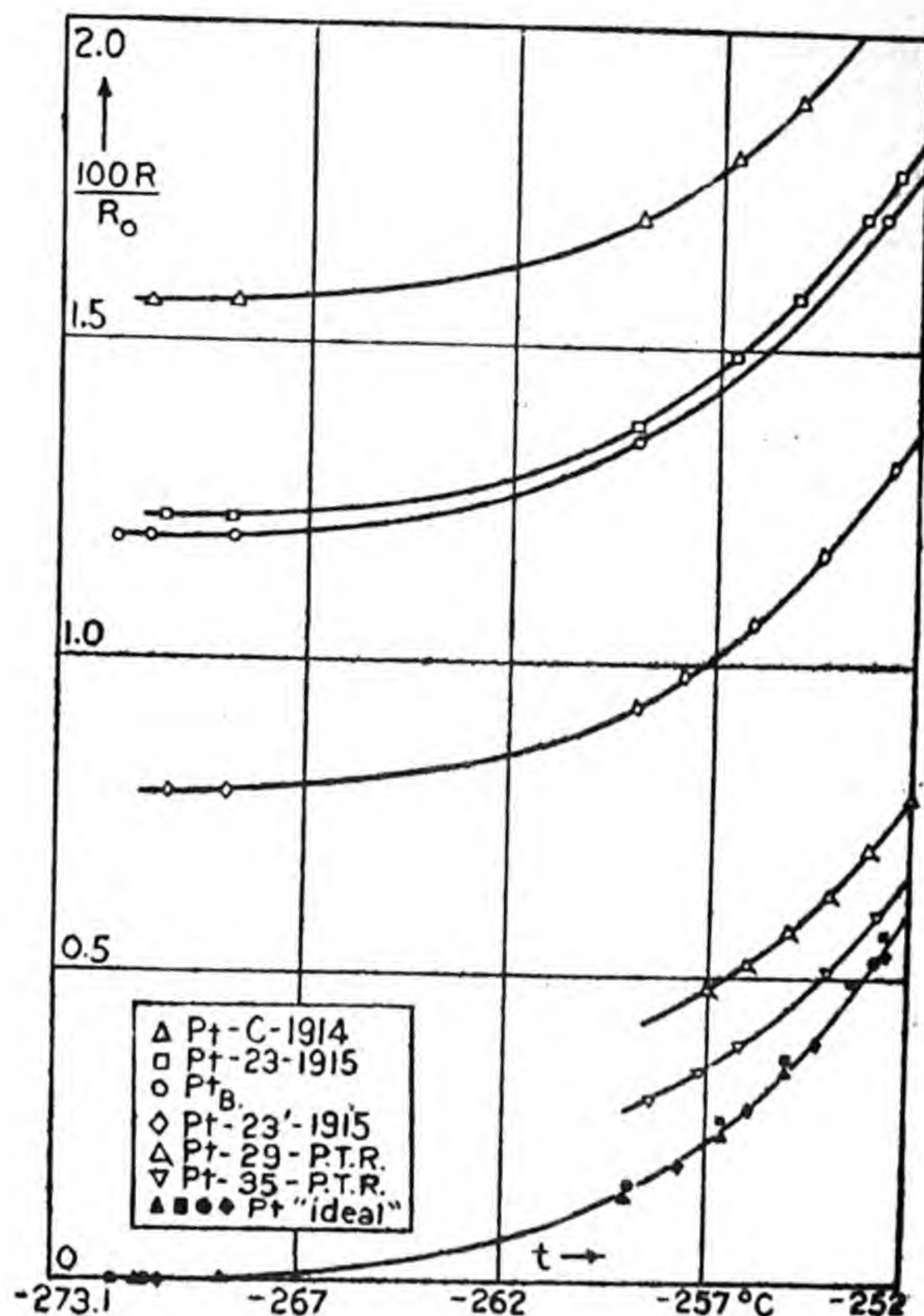
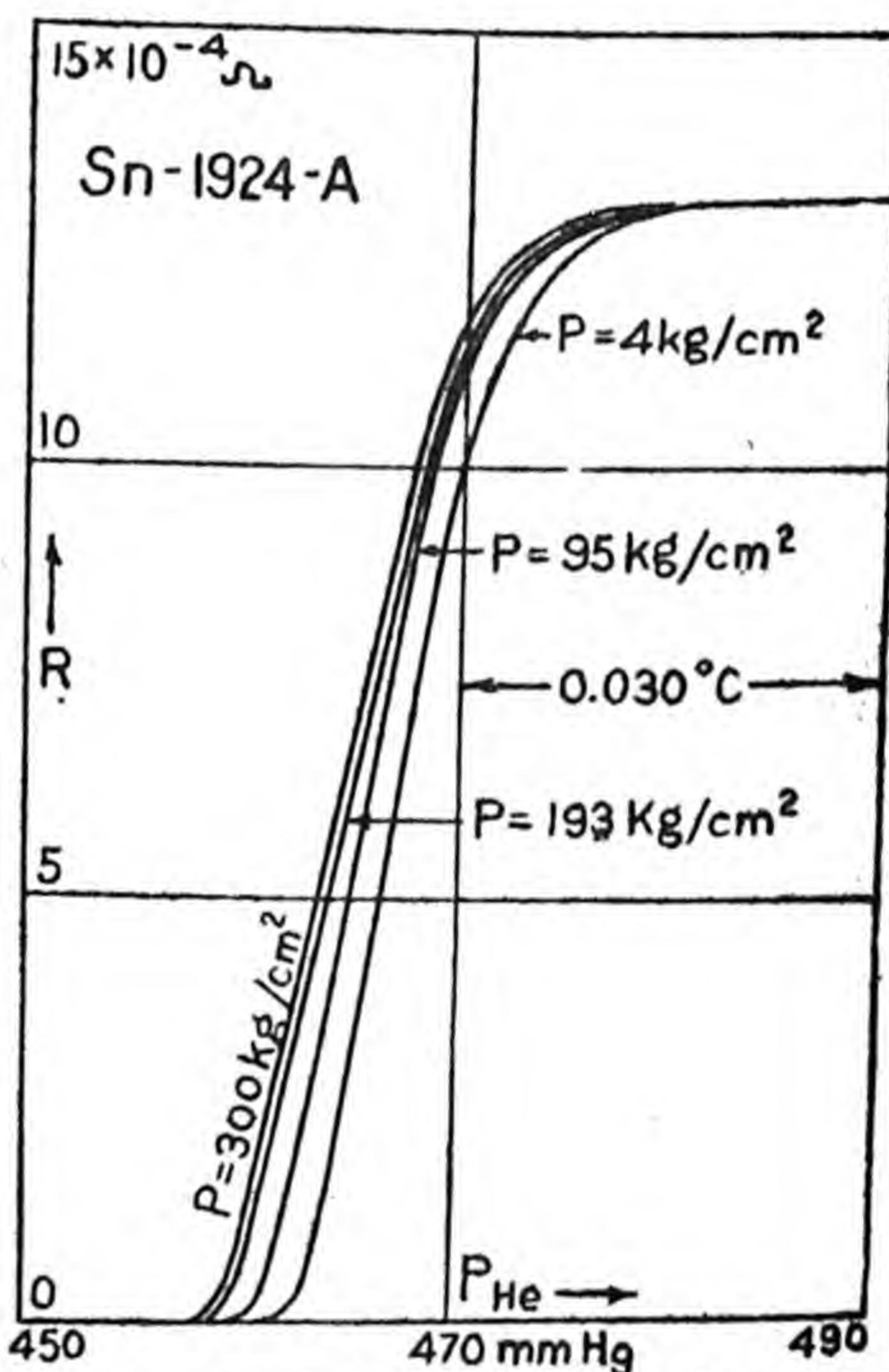


Fig. 8.—Platinum: Variation of  $R$  with temperature. Pt-C-1914 (157, 159, 160), Pt-23-1915 (19, 57, 97, 157, 160), Pt-B (112), Pt-23'-1915 (58, 160), Pt-29-P.T.R. (58, 69, 70, 73, 75), Pt-35-P.T.R. (150). For meaning of "ideal," see p. 124.





Rh.—(Cont'd)	
-t	100R/R <sub>0</sub>
160	30.2
180	21.4
191.9	16.25

Sb (41)	
-t	100R/R <sub>0</sub>
77	65.73
80	64.5
100	56.7
120	49.1
140	41.7
160	34.8
180	28.3
190	25.03

Single crystal§ (55)	
-t	100R/R <sub>0</sub>
180	63.0
81	62.6
98.9	54.5
100	54.9
102.6	53.7
110	50.7
120	47.3
120.2	47.0
120.9	47.3
130	44.3
137	40.8
140	40.0
160	32.9
180	26.3
188	23.5
191	22.8

Si (93, 94)	
-t	100R/R <sub>0</sub>
72	148
80	156
100	175
116	191
120	195
140	219
160	248
180	282
189	299

Sn (14, 157, 159, 160); see also Figs. 9, 10, 11	
-t	100R/R <sub>0</sub>
80	66.10
100	58.08
102.13	57.368
115.14	52.167
120	50.20
127.50	47.256
140	42.26
141.06	41.900
158.74	34.916
160	34.63
180	26.55
182.80	25.449
194.07	20.983
200	18.65
202.07	17.792
209.98	14.676
218.30	11.450
220	10.75
240	8.80
252.65	1.162
254.95	0.836

Sn.—(Cont'd)	
-t	100R/R <sub>0</sub>
256.61	0.637
258.89	0.409
260	0.30
268.86	0.100
269.33	0.099
269.37	Yes*

V.p. He   ¶¶ (157, 160)	
-t	100R/R <sub>0</sub>
765	0.452
480.2	0.443
476.75	0.423
474.5	0.394
471.8	0.327
470.1	0.243
467.5	0.129
466.75	0.112
465.65	0.067
465.45	0.070
463.2	0.030
463.1	0.024
461.9	0.018
461.5	0.007
461.1	0.010
458.6	0.003
456.1	Yes*

Ta (78, 83)	
-t	100R/R <sub>0</sub>
78.2	72.98
80	72.4
100	64.9
120	57.3
140	49.6
160	41.9
180	34.3
192.6	29.55

Te (4, 127)	
-t	100R/R <sub>0</sub>
80	77.3
100	73.2
102.3	72.3
110.8	71.3
120.0	69.8
131.3	67.3
140	65.9
160	62.6
180	59.6
183.1	58.9
193.1	57.9
200	56.7
203.6	55.9
220	54.7
225	54.6***
240	56.8
252.8	60.4
255.4	61.4
258.6	62.4

Ti (93, 94)	
-t	100R/R <sub>0</sub>
70	114.6
80	117.5
100	123.5

Ti.—(Cont'd)	
-t	100R/R <sub>0</sub>
120	130.6
140	139.2
160	149.6
180	161.9
191	169.0

Ti (139, 157, 159); cf. (28); see also Fig. 12	
-t	100R/R <sub>0</sub>
78.3	67.10
80	66.3
100	58.4
120	50.7
140	43.2
160	35.9
180	28.8
184.52	27.205
192.04	24.529
200	21.71
200.03	21.692
207.11	19.187
216.33	15.929
220	14.60
240	7.36
252.62	3.023
255.05	2.286
256.62	1.841
258.93	1.259
260	1.01
268.86	0.084
269.83	0.072
270.47	0.069
270.57	0.068
270.61	0.066
270.62	Yes*

W (78, 83)	
-t	100R/R <sub>0</sub>
78.35	65.09
80	64.4
100	55.7
120	46.9
140	38.2
160	29.5
180	20.8
192.8	15.29

Zn (157, 159, 160); cf. (78, 83)	
-t	100R/R <sub>0</sub>
78.2	68.62
80	67.8
100	59.7
120	51.6
140	43.5
160	35.3
180	27.1
184.37	25.367
192.05	22.136
200	18.8
200.38	18.643
206.99	15.901
215.26	12.552
220	10.8
240	4.1
252.605	1.383
255.10	1.119

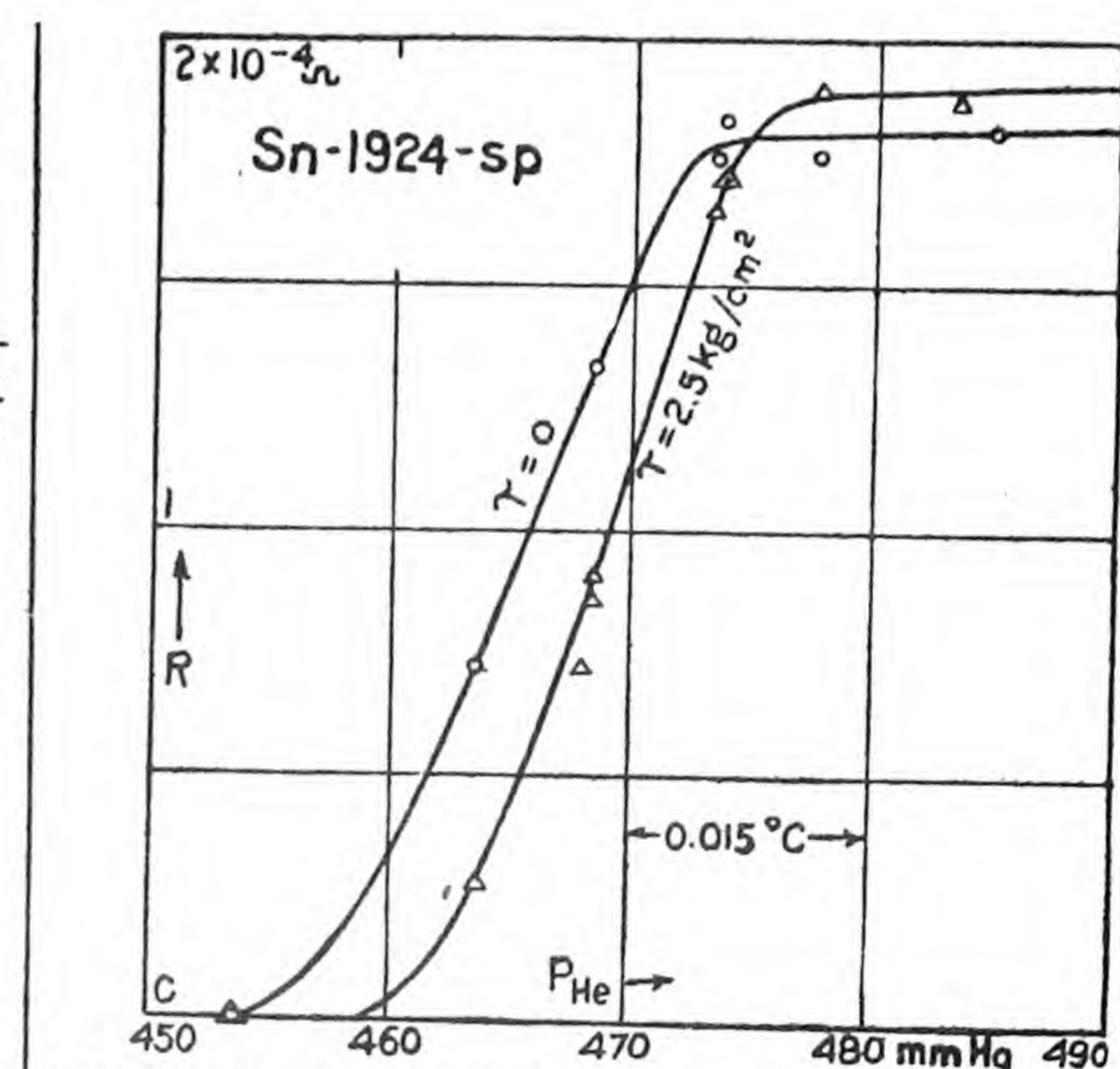


Fig. 10.—Tin: Effect of tension ( $\gamma$ ) upon the variation of  $R$  with temperature (122, 152, 154).

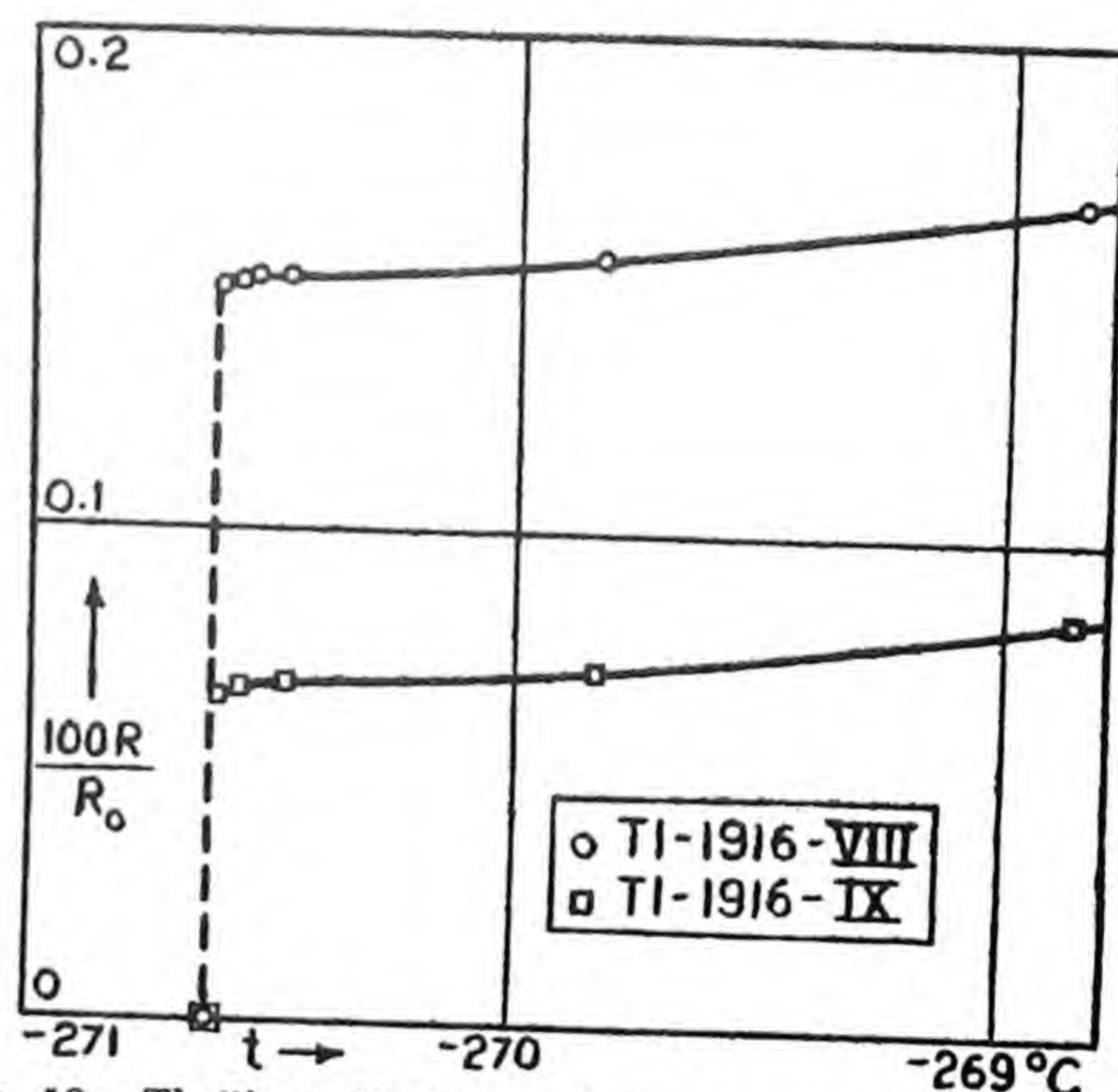
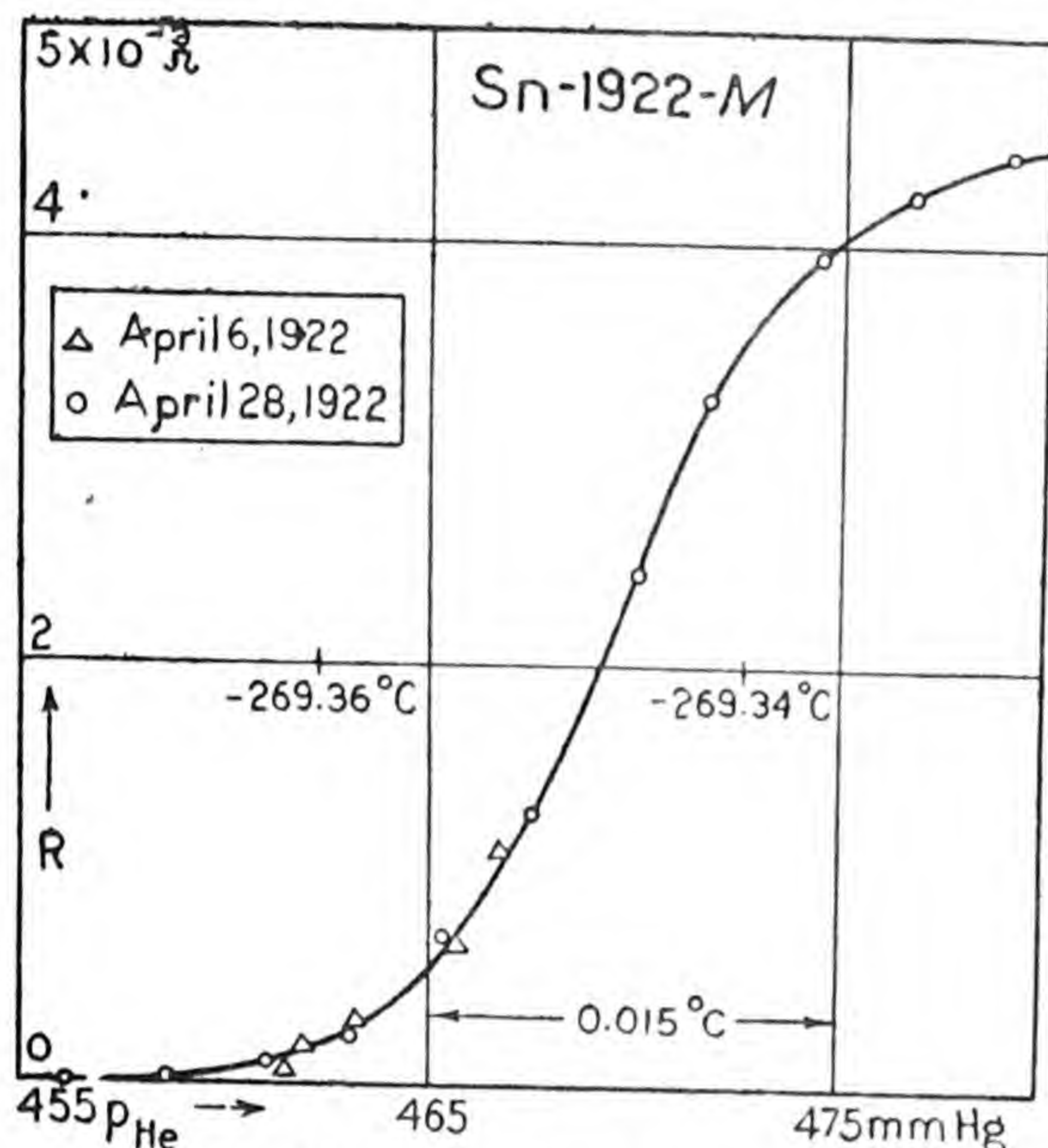


Fig. 12.—Thallium: Variation of  $R$  with temperature (139, 157).

Zn.—(Cont'd)		Zn.—(Cont'd)		Zn.—(Cont'd)	
-t	100R/R <sub>0</sub>	-t	100R/R <sub>0</sub>	-t	100R/R <sub>0</sub>
256.64	0.984	191.1	21.1	189.1	23.55
258.85	0.838	191.8	20.7	191.1	22.7
260	0.767	194.2	19.65	191.8	22.4
268.87	0.378	200	17.3	194.5	21.5
269.71	0.378	220	8.9	200	19.3
271.69	0.378	240	2.7	220	11.5
		252.65	0.749	240	3.7
		252.73	0.741	252.73	0.758
		78.2	68.1		
		80	67.3		
		100	59.2		
		120	51.2		
		140	43.2		
		143.15	41.8		
		160	35.2		
		180	27.2		
		183.4	26.0		

Zr††† (21)	
-t	100R/R <sub>0</sub>
80	66.4
100	58.4
120	50.5
140	42.7
160	35.0
180	27.4
182.87	26.261
194.93	21.851



FIG. 11.—Tin: Variation of  $R$  with temperature (157, 160).

## FOOTNOTES FOR TABLE 1

\* No = not superconducting. Yes = superconducting. A "+" after a number in the  $-t$  column indicates temperatures below that named; e.g., "265.83+" means "at temperatures below  $-265.83^{\circ}\text{C}$ ."

† Conclusion from Hall effect.

‡ Where adjacent unitalicized entries are more than  $1^{\circ}$  apart for Au, or  $5^{\circ}$  for Pb, a linear interpolation introduces an error of less than one unit in the last figure.

§  $\perp$ ,  $\parallel$ . Denotes that the single crystal is cut or split  $\perp$ ,  $\parallel$ , to the crystallographic  $c$ -axis and that the current passes  $\perp$ ,  $\parallel$ , to that axis.

¶ Commercial electrolytic copper. ¶ Natural copper crystals. \*\* Kolawa iron.

†† Temperature deduced from vapor pressure of He (see Note ¶¶). For Ga, the magnetic field was 17 gauss.

‡‡ In  $R/R_0$ , the  $R_0$  refers to solid Hg, and is obtained by extrapolation.

§§ Resistance  $R$  computed from observed current and potential difference, assuming Ohm's law. Region of transition from ordinary to superconductivity.

¶¶ V.p. He = pressure of saturated vapor of He at temperature of observation; unit = 1 mm of Hg.

V.p. He.....	765	480.2	461.9	456.1	394.4
$-t$ .....	268.88	269.33	269.36	269.37	269.49
V.p. He.....	339.6	309.8	304.0	45	8
$-t$ .....	269.61	269.67	269.69	270.74	271.5

\*\*\* Approximately minimum value.

††† Data from (93, 94) differ greatly from those of (21), and indicate  $R$  has a minimum near  $-80^{\circ}\text{C}$ .

TABLE 2.—RESISTANCE OF PLATINUM BELOW  $-80^{\circ}\text{C}$  (19, 75, 87, 88, 97, 157, 160)

I = Pt-23-1915 (19, 87, 97, 157, 160); II = Pt-23'-1915 (88, 160); III = Pt-29-P.T.R. (75); see also Fig. 8.  $R, R_0$  = resistance (not resistivity) of the specimen at temperature  $t$ ,  $^{\circ}\text{C}$ ,  $0^{\circ}\text{C}$ .  $t$  = centigrade temperature,  $^{\circ}\text{C}$ ; every  $t$  is negative.

$-t$	$100R/R_0$		
	I	II	III
80	68.158	68.017	67.782
82	67.350	67.205	66.964
84	66.542	66.393	66.146
86	65.733	65.581	65.328
88	64.923	64.769	64.508
90	64.113	63.955	63.688
92	63.303	63.141	62.866

TABLE 2.—(Continued)

$-t$	$100R/R_0$		
	I	II	III
94	62.492	62.325	62.044
96	61.680	61.509	61.222
98	60.867	60.692	60.400
100	60.053	59.874	59.576
102	59.237	59.055	58.752
104	58.421	58.235	57.926
106	57.605	57.415	57.100
108	56.788	56.593	56.274
110	55.970	55.771	55.446
112	55.150	54.949	54.618
114	54.329	54.125	53.788
116	53.507	53.301	52.958
118	52.685	52.476	52.127
120	51.863	51.650	51.295
122	51.039	50.823	50.463
124	50.215	49.995	49.629
126	49.391	49.167	48.795
128	48.567	48.337	47.959
130	47.741	47.507	47.123
132	46.915	46.675	46.286
134	46.087	45.842	45.448
136	45.257	45.008	44.609
138	44.427	44.173	43.769
140	43.595	43.337	42.928
142	42.761	42.500	42.086
144	41.927	41.661	41.244
146	41.092	40.821	40.401
148	40.255	39.979	39.555
150	39.418	39.135	38.709
152	38.580	38.291	37.861
154	37.740	37.446	37.013
156	36.899	36.600	36.164
158	36.057	35.752	35.314
160	35.213	34.904	34.463
162	34.367	34.054	33.609
164	33.519	33.204	32.755
166	32.670	32.353	31.901
168	31.820	31.501	31.045
170	30.970	30.647	30.189
172	30.120	29.793	29.331
174	29.268	28.937	28.471
176	28.416	28.079	27.611
178	27.563	27.219	26.749
180	26.709	26.356	25.885
182	25.855	25.491	25.020
184	25.001	24.625	24.154
186	24.146	23.758	23.285
188	23.292	22.893	22.416
190	22.438	22.030	21.551
192	21.584	21.169	20.689
194	20.730	20.311	19.830
196	19.876	19.455	18.974
198	19.024	18.601	18.120
200	18.176	17.750	17.268
201	17.754	17.326	
202	17.333	16.903	
203	16.913	16.481	
204	16.494	16.060	
205	16.076	15.640	
206	15.659	15.221	
207	15.244	14.804	
208	14.831	14.389	



TABLE 2.—(Continued)

$-t$	$100R/R_0$		
	I	II	III
209	14.419	13.975	
210	14.009	13.563	
211	13.601	13.153	
212	13.195	12.745	
213	12.791	12.339	
214	12.390	11.936	
215	11.993	11.536	
216	11.599	11.139	
217	11.208	10.745	
218	10.821	10.355	
219		9.969	
220		9.587	
221		9.209	
222		8.835	
223		8.466	
224		8.102	
225		7.743	
226		7.389	
227		7.040	
228		6.697	
229		6.360	
230		6.030	
231		5.708	
232		5.395	
233		5.092	
234		4.799	
235		4.516	
236		4.243	
237		3.980	
238		3.727	
239		3.484	

TABLE 2.—(Continued)

$-t$	$100R/R_0$		
	I	II	III
240		3.252	
241		3.031	
242		2.821	
243		2.623	
244		2.437	
245		2.263	
246		2.101	
247		1.952	
248		1.815	
249		1.688	
250		1.571	
251		1.464	
252	1.8422	1.3661	0.7902
253	1.7474	1.2773	0.7048
254	1.6630	1.1974	0.6320
255	1.5885	1.1263	0.5706
256	1.5227	1.0637	0.5198
257	1.4649	1.0095	0.4788
258	1.4147	0.9635	
259	1.3717	0.9255	
260	1.3355	0.8945	
261	1.306	0.8695	
262	1.2825	0.8495	
263	1.264	0.8335	
264	1.2495	0.8205	
265	1.239	0.810	
266	1.2325	0.8015	
267	1.2285	0.795	
268	1.226	0.7905	
269	1.2241	0.7879	
270	1.2225	0.7863	

TABLE 3.—EFFECT OF IMPURITIES, STRESS, HEAT TREATMENT, ETC., UPON RESISTANCE OF ELEMENTARY SUBSTANCES AT LOW TEMPERATURES

B = bar, section is circular unless another form is indicated, (c) = specimen was cast, (cd) = cold drawn, (cp) = cold pressed, (crl) = crystalline, Cryst = single crystal, (d) = distilled, (D) = drawn through diamond die, new diamonds, Diamag = diamagnetic, (dr) = drawn, Elec = electrolytic, (ex) = extruded while hot, (f) = filed, Fil = filament from incandescent electric lamp, Fv = fused in vacuo, FW = wire which has been flattened by hammering or by rolling, G = specimen was cast (c) or distilled (d) into a straight glass tube, Glo = specimen was annealed by glowing, (hd) = hard drawn, (H) = wire was drawn by Heraeus,  $l$  = length, M = malleable and ductile, P = plate, (p) = pressed, P.T.R. = Physikalisch-Technische Reichsanstalt, (r) = rolled, S = strip, Super = superconductive, (t) = turned or cut on lathe, tr. = trace, UG = same as G except that tube is U-shaped, Vac = resistance of specimen measured in vacuo, W = wire;  $\square$ ,  $\square$  = section is rectangular, is square;  $\perp$  = crystal is cut perpendicularly to the crystallographic (c) axis of trigonal symmetry. The dimension of the specimen (unit = 1 mm) is indicated by subscripts (if only one is given, the specimen is cylindrical, or is a thin narrow strip, and the subscript is its diameter, or the width of the strip); e.g.,  $W_{0.5}$  = wire 0.5 mm in diameter,  $B_{24,4,4.1}$  = bar 24 mm long, section 4 mm by 4.1 mm. In the column headed "Annealed," is given the annealing temperature, if known; "Yes" = annealed, "No" = not annealed. In the second column is given the date of publication or of measurement. Centigrade temperatures. Unit of length = 1 mm; of  $p$ , pressure, = 1 atm., of  $\Delta R/pR$  = 1 (atm.) $^{-1}$ ;  $-182.95^{\circ}$ ,  $-252.76^{\circ}$ ,  $-268.88^{\circ}$  = boiling point of O, H, He at 1 atm.

	Date	Source and designation	Impurities	Form and size	Annealed	$100R/R_0$				Lit.
						$-182.95^{\circ}$	$-192^{\circ}$	$-252.76^{\circ}$	$-268.88^{\circ}$	
Ag	1892	Pure Ag.....		W		30.3	26.9			(27)
	1904	Agst.....				27.9	24.3			(26)
	1907	Kahlbaum.....		$W_{0.5}(\text{dr})$		30.0	26.8			(110)
	1907; 8	C. Hoitsema.....	0.18 %	$W_{0.1}(\text{H})$		25.0*	21.1*	0.90*		(22, 132)
	1912	C. Hoitsema.....	0.18 % ca.	Po.005		22.8	18.8	0.91		(3, 4, 124)
	1913	Heraeus, AgI.....	Chem. pure		Yes	25.39	21.4	1.47		{ (146, 147)
		Heraeus, AgII.....	Chem. pure		No	26.1	22.36	2.32		
	1919; 20	Heraeus.....		$W_{0.1}$	500°	24.6	20.71	0.54		(78, 79, 83)
	1892	Pure Al.....		W(hd)		28.3	24.6			(27)
	1893	Commercial Al.....	2.5 %	$W_{0.25}$		19.0	15.6			(28)
Al		Neuhausen Al.....	1 %	$W_{0.25}$		21.8	18.1			(28)
	1907	Kahlbaum.....		$W_{0.5}(\text{dr})$		26.8	23.3			(110)
	1919	AlII.....	1.6 % (Fe + Si)	$W_{0.2 \text{ to } 0.25}$	220°		17.80			(78)
					250°†		17.60			(78)
		AlIII.....	1.2 % (Fe + Si)	$W_{0.2 \text{ to } 0.25}$	220°		14.78			(78, 83)
					250°†		14.51			(78, 83)



TABLE 3.—(Continued)

	Date	Source and designation	Impurities	Form and size	Annealed	100R/R <sub>0</sub>				Lit.
						-182.95°	-192°	-252.76°	-268.88°	
Al	1919; 20	Aliv	0.4 % (Fe + Si)	W <sub>0.1</sub> to 0.25	225°		15.72			
					250°†	18.9*	14.91*	4.27*		
					300°		15.64			(78, 79, 83)
					500°		18.88			
					600°		21.61			
		Mylius, Alv	0.1 % (Fe + Si)	W <sub>0.1</sub> to 0.25	225°		17.56			
					250°		17.53			
					250°†	21.4	17.39	5.94		(78, 79, 83)
					300°		18.14			
					500°		20.40			
	1924; 26	Bureau of Standards	Fe = 0.18 % Si = 0.15 % Purest	W <sub>0.1</sub> (cd)					6.77	(157, 160)
Au	1901	Roberts Austen, Au <sub>0</sub>				29.2	25.5	3.29		(25)
	1904	Same as Au <sub>0</sub> (?), Au <sub>33</sub>				34.7	31.3	11.18		(26)
	1907	Kahlbaum		W <sub>0.1</sub> (dr)		32.7	29.6			(110)
	1906; 8	C. Hoitsema, Au <sub>0</sub>	0.03 %	W <sub>0.1</sub> (H)		30.07	26.27	4.579		(22, 121, 123)
	1907; 08; 11	C. Hoitsema, Au <sub>III</sub>	0.015 %	W <sub>0.1</sub> (H)	Yes	27.65	23.88	1.627	1.020	(22, 116, 123)
	1907; 8	C. Hoitsema, Au <sub>IV</sub>	0.005 %	W <sub>0.1</sub> (H)	Yes	27.18	23.39	0.890		(22, 123)
		C. Hoitsema, Au <sub>V</sub>	0.005 %	W <sub>0.1</sub> (H)	Yes	27.10	23.30	0.835		(22, 123)
	1912	C. Hoitsema	<0.03 %	P <sub>0.1</sub>		28.7	25.1	3.5		(3, 4, 124)
	1913	Heraeus, Au <sub>I</sub>	Chem. pure	W	Glo	27.4	24.00	1.90		
		Heraeus, Au <sub>II</sub>	Chem. pure	W	No	28.3	24.03	2.93		
		Handelsmetall Anst., Au <sub>III</sub>	0.01 %, Elec	W	Glo	27.8	24.40	2.23		(146, 147)
		Handelsmetall Anst., Au <sub>IV</sub>	0.01 %, Elec	W	No	28.7	25.31	3.43		
	1915	Mylius	0.001 %	Cast		27.1	23.1	0.69		(83, 102)
	1917	C. Hoitsema, Au-11-1915	Minting†	W <sub>0.1</sub> (D)	Glo‡	27.08*	23.27*	0.825*	0.223*	(14, 17, 18)
		C. Hoitsema, Au-12-1915	Minting†	W <sub>0.04</sub> (D)	Glo‡	27.20	23.40	0.891		(17, 18)
	1919; 20	(?)		W <sub>0.1</sub>	500°	27.5	23.75	0.68		(78, 79, 83)
	1923	Mylius	0.001 %	W <sub>0.15</sub> (dr)	No	28.03	24.3	1.9	1.073	(104)
		Mylius	0.001 %	W <sub>0.15</sub> (dr)	350°		23.15	0.698	0.109	(104)
		Mylius, Au-1a	0.001 %	Cryst			23.03	0.674	0.093	(104)
		Mylius, Au-1b	0.001 %	Cryst			22.96	0.633	0.039	(104)
Bi	1897	Hartmann and Braun	Pure, Elec	W <sub>0.1</sub> (p)		39.0	35.8			(32)
	1907; 8	Hartmann and Braun, No. 301		Spiral		41.35*	39.2*	22.43*		(22, 123)
	1913	Kahlbaum	0.07 % ca.	B <sub>15</sub> (c)		37.7	33.8			(41)
Cd	1919	Mylius and Groschuff	Pure	W <sub>0.1</sub> (p)	200°	38.6	35.59			(78, 83)
	1893	Matthey	Pure	W <sub>0.7</sub> (dr)		29.5	25.8			(28)
	1912	Kahlbaum		B		30.3	26.8			(37)
	1913	Kahlbaum, Cd <sub>I</sub>	<0.01 %	W(cd)		28.78	25.20	2.36		(146, 147)
		Kahlbaum, Cd <sub>II</sub>	<0.01 %	W(ex)		28.66	25.09	2.21		(146, 147)
	1914	Kahlbaum	<0.01 %	G(c)		29.2	25.6	2.06	0.04	(127)
	1919; 20	Kahlbaum, Cd <sub>I</sub>	<0.01 %	W <sub>0.1</sub>	220°	29.0	25.34	2.14		(78, 79, 83)
	1924; 26	Kahlbaum, Cd-1920-I	<0.01 %	W <sub>0.15</sub> (ex)		28.70*	25.15*	2.23*	0.143*	(157, 159, 160)
		Kahlbaum, Cd-1919-I		W <sub>0.12</sub> (ex)		March, 1920	Change with time		0.327	
		Kahlbaum, Cd-1919-I		W <sub>0.12</sub> (ex)		January, 19-3			0.290	(157, 160)
Co	1921	Heraeus, Co <sub>I</sub>		W <sub>0.15</sub>	500°		16.10			(80)
		Kahlbaum, Co <sub>II</sub>	(F <sub>V</sub> in SiO <sub>2</sub> )		500°		13.5*			(80)
Ca	1908	Hackspill's method		UG <sub>0.1</sub> to 1(d)		29.3	26.3			(52, 53, 54)
	1910	Hackspill's method, tube 3		G <sub>10</sub> to 30(d)		28.6*	25.9*			(57)
Cu	1885	Electrolytic conductivity = 98 %		Coil		21.3	17.5			(166)
	1901	Johnson and Matthey				19.6	15.8	0.98		(28)
	1907	Kahlbaum		W <sub>0.1</sub> (dr)		20.8	18.4			(110)
	1912	Felten and Guillaume	Elec			16.3	12.3	1.04		(5, 4, 124)
	1913	Leppin and Masche	Diamag	W(cd)		19.9	16.16	1.78		(146, 147)
	1914; 21	Kahlbaum, Cu <sub>I</sub> , Cu <sub>II</sub>		W(H)				0.85		(68, 69)
		Siemens and Halske, Cu <sub>II</sub> , Cu <sub>III</sub>		W		18.87*	15.0*	0.63*		(68, 69)
	1915	Siemens and Halske, Cu <sub>I</sub>	Elec Diamag	W not (dr)	No	18.4	14.4	0.28		(82, 102)
		Electrolytic, Cu <sub>II</sub>	Elec	W(dr)	Glo	19.2	15.3	1.13		(82, 102)
		Felten and Guillaume	Elec	S(f)				1.35		(90)
		Felten and Guillaume	Elec	S(r)				2.42		(90)
		Felten and Guillaume	Elec	S(r)	Yes			1.098		(90)
	1916	Commercial Cu		B		20.1	16.4	2.00		(149)
	1919; 20	Siemens and Halske, Cu <sub>I</sub>		W <sub>0.1</sub>	380°†	18.7	14.75	0.63		
		Siemens and Halske, Cu <sub>I</sub>		W <sub>0.1</sub>	500°	19.0	15.02			(78, 79, 83)
	1913	Natural crystals, Cu-b						0.27	0.11	(123, 157, 160)
	1916	Lake Michigan, crystal		B(t)			13.3	0.12		(149)
	1924; 26	Natural crystals, Cu <sub>III</sub>				18.16	14.40	0.158		(157, 159, 160)
Fe	1893	Armstrong's	Mg = 0.25 % S = 0.01 %	W <sub>0.17</sub> (cd)		22.3	19.7			(28)
		Hopkins and Williams	Very soft	W <sub>0.15</sub>	Yes	13.5	10.2			(28)
	1901	(?), Fe <sub>m</sub>				22.9	20.3	12.88		(28)
	1907	Kahlbaum		W <sub>0.1</sub> (dr)		26.5	23.7			(110)
	1912	Kolsa (Sweden)	0.18 % (C, S, P, Si, Mn)			21.8	19.1	11.07		(4, 125)
	1913	Hartmann and Braun, Fe <sub>I</sub>	Elec	W(dr)	Glo	13.8	10.54	2.80		
		Hartmann and Braun, Fe <sub>II</sub>	Elec	W(dr)	No		11.09	3.30		(146, 147)



TABLE 3.—(Continued)

	Date	Source and designation	Impurities	Form and size	Annealed	100R/R <sub>0</sub>				Lit.
						-182.95°	-192°	-252.76°	-268.88°	
Fe	1919	Electrolytic, Fe <sub>1</sub> .....	Elec, F <sub>v</sub>	W <sub>0.1</sub>	300°	13.2	9.98			(78, 83)
		Electrolytic, Fe <sub>11</sub> .....	Elec, F <sub>v</sub>	W <sub>0.1</sub>	500°	13.2	10.03			(78, 83)
	1919; 20	Kahlbaum, Fe <sub>11</sub> .....	0.01 %	W <sub>0.1</sub> (dr)	380°†	12.1*	8.78*	1.13*		(78, 79, 83)
Ge	1922	Dennis.....	<0.1 %	B <sub>24,4,4-1</sub>		97.5*	101*			(8)
Hg	1914	(R <sub>0</sub> extrapolated for solid Hg).....				28.5*	25.4*	4.90*	0.176*	(137)
In	1924	de Haën, In-1922-II.....	Chem. pure	W <sub>0.17</sub> (ex)		28.70*	25.55*	5.72*	3.394*	(187, 188, 189)
		For effect of pressure, see Fig. 6								
Ir	1911	Heraeus.....		□FW		32.5	29.5			(13)
	1919	P.T.R., Ir <sub>1</sub> .....		W <sub>1</sub>	600°	26.3*	22.54*			(78, 83)
K	1901	Johnson and Matthey.....				26.6	22.6	2.86		(25)
	1908	Hackspill's method.....		UG <sub>0.1 to 1</sub> (d)		31.8	29.0			(52, 53, 54)
	1924	Merok, K-1916-III.....	F <sub>v</sub>	UG(d)		27.19*	24.0*	2.70*	0.702*	(164, 165)
Li	1908	Purified.....	K and Na free	UG <sub>0.1 to 1</sub> (d)		17.3	13.8			(52, 54)
	1920	Kahlbaum.....		B		17.0*	13.4*	0.73*		(103)
Mg	1893	Matthey.....	Zn free	W <sub>0.1</sub>		23.0*	19.3*			(28)
	1907	Carlo Elba.....		W <sub>0.1</sub> (dr)		31.7	28.5			(110)
Mo	1919	D. Gasglühlicht Ges., Mo <sub>11</sub> .....		W <sub>0.25</sub> Vac	500°	22.9*	19.31*			(78, 83)
		(?), Mo <sub>1</sub> .....	Impure	W <sub>0.25</sub> Vac	500°	27.0	23.65			(78, 83)
Na	1908	Hackspill's method.....		UG <sub>0.1 to 1</sub> (d)		21.9	18.1			(52, 53, 54)
	1910	Hackspill's method, tube 3.....		G <sub>10 to 20</sub> (d)		22.7				(57)
	1924	Kahlbaum, Na-1916-IV.....	F <sub>v</sub>	UG(d)		24.40*	20.8*	0.91*	0.381*	(164, 165)
		Kahlbaum, Na-1916-V.....	F <sub>v</sub>	UG(d)				1.00	0.474	(164, 165)
Ni	1892; 93	Dr. Ludwig Mond.....		Spiral (t)		15.5	12.6			(27, 28)
	1900	Electrolytic.....	Elec	W <sub>0.1</sub> (dr)	Yes	20.8*	17.8*			(40)
	1904	Johnson and Matthey, Ni <sub>41</sub> .....				20.8*	17.8*	8.55		(26)
	1907	Kahlbaum.....		W <sub>0.1</sub> (dr)		20.1	17.3			(110)
	1909	Hartmann and Braun, "Reinnickel".....	1 % (Mn, Cu, Fe)	W <sub>0.025</sub>		28.2	25.3			(10)
	1912	"Schwerte" Ni.....	Pure	P <sub>0.053</sub>		33.3	30.8	20.46		(4, 125)
	1913	Hartmann and Braun.....		W		31.8	29.2	20.5		(146, 147)
	1919				500°†					(78)
	1921	Kahlbaum, ID.....	0.5 %	W <sub>0.1</sub> (ex)	200°(?)		15.40			(80)
		Heraeus, IIB.....	0.05 %	W(ex)	500°		10.39			(80)
		Heraeus, IID.....	0.05 %	W(ex)	500°		10.1			(80)
	Pb	1893	Matthey (1884).....	Very pure	W <sub>0.7</sub> (cp)		29.6	26.4		
1907		Kahlbaum.....		W <sub>0.1</sub> (dr)		35.7	32.7			(110)
1907; 8		(?).....	0.015 %	S(t)		29.69	26.40	3.04		(22, 133)
1912		(?).....		W <sub>0.1</sub>		31.6	28.2	6.1		(126)
1913		Kahlbaum, Pb <sub>1</sub> .....	<0.01 %	W(cd)		30.8	27.43	4.68		(146, 147)
		Kahlbaum, Pb <sub>111</sub> .....	<0.01 %	W(ex)		31.0	27.64	4.61		(146, 147)
1913; 14; 21		Nernst.....		W <sub>0.1</sub>		30.5	27.3	4.37		(63, 65, 69)
		Kahlbaum.....	<0.01 %	W <sub>0.1</sub> (dr)		29.6	26.35	3.10		(63, 65, 69, 83)
1915; 25; 26		Kahlbaum.....	<0.01 %	B <sub>2</sub> (t)		29.7	26.4	3.02	Super	(83, 102, 104, 105)
1915		Kahlbaum.....	<0.01 %	S cut				2.96		(90)
		Kahlbaum.....	<0.01 %	S(r)				2.96		(90)
1919; 20		Kahlbaum.....	<0.01 %		200°	29.6	26.34	3.05		(78, 79, 83)
1924; 26	Kahlbaum, Pb-1919-I.....	<0.01 %	W <sub>0.12</sub> (ex)		29.53*	26.19*	2.96*	Super*	(140, 157, 159, 160)	
$t = -183^{\circ}, p = 49, 10^8 \Delta R/pR = -2.32; p = 100, 10^8 \Delta R/pR = -2.2; t = -252.8^{\circ}, p = 49.7 \text{ or } = 100, 10^8 \Delta R/pR = -1.7$ (126)										
Pd	1893	Matthey.....	Very pure	W <sub>0.25</sub>		27.2	23.6			(28)
	1904	Johnson and Matthey, Pd <sub>48</sub> .....				27.8	24.2	6.05		(26)
	1912	Heraeus.....		P <sub>0.100</sub>	Yes			5.15		(4, 124)
	1919; 20	Heraeus, Pd <sub>1</sub> .....		W <sub>0.1</sub> Vac(?)	500°	22.9*	18.74*	0.93*		(78, 79, 83)
	1919	Heraeus, Pd <sub>2</sub> .....		W <sub>0.1</sub> air	500°	23.7	19.70			(78, 83)
Pt	1892	(Pure soft).....	Pure	W	Yes	33.3	29.7			(27)
	1893	Johnson and Matthey, Pt <sub>1</sub> .....		W <sub>0.26</sub>		30.5	26.9	5.90		(25, 28)
		Matthey.....		W <sub>0.01</sub>		27.9				(28)
	1896	Heraeus.....		W <sub>0.05</sub>		31.4	27.5			(54, 55)
	1901; 21	Cambridge Sci. Inst. Co., Pt <sub>1</sub> .....		W		25.482	21.59	1.694		(65, 69, 76, 77)
	1903	Heraeus, I.....	Chem. pure	W <sub>0.01</sub>	Glo	28.3	24.6			(6, 7)
		Heraeus, II.....	Chem. pure	W <sub>0.1</sub>	Glo	25.5	21.6			(6, 7)
	1904; 7; 8	(?), Pt <sub>M</sub> .....		W <sub>0.1</sub>		25.936	22.113			(22, 98, 100, 132)
	1904	Johnson and Matthey, Pt <sub>1</sub> .....				26.3	22.3	2.42		(26)
	1905	"Standard Pt".....		W			20.90			(155)
	1906; 8; etc.	Heraeus, Pt <sub>1</sub> '.....		W <sub>0.1</sub> (dr)	Yes	25.178	21.287	1.418		(22, 86, 97, 128, 129, 130, 132, 136)
	1907; 8	Heraeus, Pt <sub>111</sub> .....		W <sub>0.1</sub>	Yes	25.068	21.205			(22, 132)
		Heraeus, Pt <sub>IV</sub> or V.....		W <sub>0.1</sub>	Yes¶	25.012	21.161			(22, 132)
		Heraeus, Pt <sub>d</sub> .....		W <sub>0.05</sub>		27.288	23.599	4.062		(22, 132)
1907	Kahlbaum.....		W <sub>0.1</sub> (dr)		34.5	31.2			(110)	
1911	Heraeus, Pt <sub>B</sub> .....		W <sub>0.01</sub> **				1.72	1.19	(112)	
1913; 21; 24	Heraeus, Pt <sub>2</sub> .....		W <sub>0.01</sub> ††		24.610*	20.689*	0.724*		(62, 63, 65, 69, 70, 72, 73, 74, 75)	
		Heraeus, Pt <sub>2</sub> .....		W <sub>0.01</sub> ††		24.617	20.695	0.737		(62, 63, 65, 67, 69, 72, 73, 74)
		Heraeus, Pt <sub>21</sub> .....		W <sub>0.01</sub> ††		24.629	20.689	0.743		(62, 63, 65, 69, 71, 72, 74, 83)
1915	Heraeus.....			W <sub>2</sub>	Glo	24.5	20.6	0.60		(102)



TABLE 3.—(Continued)

Pt	Date	Source and designation	Impurities	Form and size	Annealed	100R/R <sub>0</sub>				Lit.
						-182.95°	-192°	-252.76°	-268.88°	
Pt	1915	Heraeus, Pt <sub>33</sub> .....		W						(150)
	1915; etc.	Heraeus, Pt-22-1915.....	Very pure	W <sub>0.05</sub> (D)	Glo§	25.823		2.153	0.600 <sub>8</sub>	(19)
		Heraeus, Pt-23-1915.....	Very pure	W <sub>0.05</sub> (D)	Glo§	25.449*	21.584*	1.771*	1.224*	(19, 87, 97, 157, 160)
	1915	Heraeus, Pt-24-1915.....	Very pure	W <sub>0.05</sub> (D)	Glo§	25.420		1.775		(19)
	1917	Heraeus, Pt-21-1915.....	Very pure	W <sub>0.05</sub> (D)	Glo§	25.038	21.136	1.219		(17, 18, 97)
	1917	Heraeus, Pt-26-1915.....	Very pure	W <sub>0.1</sub> (D)	Glo§	24.808	20.901	1.000		(17, 18)
	1919	Heraeus.....		W	800°†	24.5	20.60	0.60		(78, 79)
	1921	Heraeus, Pt <sub>33</sub> .....		W	Yes§§	24.700	20.78	0.819		(65, 69)
		Heraeus, Pt <sub>34</sub> .....		W	Yes§§	24.682	20.76	0.806 <sub>5</sub>		(65, 69)
		Heraeus, Pt <sub>35</sub> .....		W	Yes§§	24.528	20.60	0.610		(65, 69)
	1922	(?).....		W <sub>0.16</sub>		24.90				(91)
	1923; 25; 26	Heraeus, Pt-23'-1915.....		W <sub>0.05</sub> (D)	Glo§§	25.080*	21.169*	1.298*	0.788*	(88, 160)
	1923; 25	Heraeus, Pt-27'-1915.....		W <sub>0.05</sub> (D)	Glo§§	25.176	21.262			(88)
		Heraeus, Pt-31-1920.....		W <sub>0.05</sub> (dr)	Glo§§	25.662	21.788	1.906		(88)
		Heraeus, Pt-32-1920.....		W <sub>0.05</sub> (dr)	Glo§§	25.670	21.797	1.920		(88)
		Heraeus, Pt-36-1922.....		W <sub>0.05</sub> (dr)	Glo§§	25.463	21.577	1.639		(88)
	1924; 26	P.T.R.(?), Pt-C-1914.....		W <sub>0.14</sub>		25.723		2.068	1.559	(157, 159, 160)
		P.T.R.(?), Pt-D-1914.....		W <sub>0.14</sub>		25.563	21.697	1.873	1.372	(157, 159, 160)
Rb	1908	Hackspill's method.....		UG <sub>0.5</sub> to 1(d)		28.1	25.6			(52, 53, 54)
Rb	1910	Hackspill's method, tube 5.....		G <sub>10</sub> to 20(d)		23.2*	21.2*			(57)
Rb	1911	Heraeus.....		FW□		16.4	11.6			(13)
Sb	1913	P.T.R., Rb <sub>1</sub> .....		W <sub>1</sub> (r)	600°	20.1*	16.19*			(78, 83)
Si	1913	Kahlbaum.....	0.05 % ca.	B <sub>25</sub> (c)		27.3*	24.4*			(41)
Si	1913	Merck.....	Pure	Cryst ⊥		25.3*	22.5*			(58)
Si	1913	de Haën.....	Some H <sub>2</sub> SiO <sub>4</sub> ?	B		288*	304*			(93, 94)
Sn	1893	(?).....	Pure	W <sub>0.05</sub> (ex)		26.0	22.4			(28)
Sn	1914	Kahlbaum.....	<0.01 %	S(t)		26.4	22.5	1.21	0.052	(137)
Sn	1923	Kahlbaum, Sn-1922-III.....	<0.01 %	W <sub>0.05</sub> (ex)		25.83	22.25	1.18	0.075	(159)
Sn	1924; 26	Kahlbaum, Sn-1922-A.....	<0.01 %	So <sub>05</sub> (FW)		25.39*	21.80*	1.15*	0.100*	(157, 159, 160)
Sn	1925	Kahlbaum, Sn-1922-I.....	<0.01 %	W <sub>0.15</sub> (ex)		26.28	22.65	1.22	0.079	(157, 159, 160)
Ta	1919	For effect of stress, see Figs. 10, 11.....				25.36	21.66	1.20	0.079	(104)
Te	1908	Lamp filament.....		Fil	2200°	33.2*	29.78*			(78, 83)
Te	1912	Commercial, purified.....		B <sub>5</sub> to 7, l = 20 to 30		61	59			(52, 54)
Ti	1908	Merck, purest.....		P <sub>1</sub> 88 ¶¶		59.1*	57.8*	60.4*		(4, 127)
Ti	1893	de Haën.....	tr. (Fe, Si)	B		164*	170*			(93, 94)
Tl	1922; 24	Ramsay.....		W <sub>0.1</sub> (cp)		27.7	24.5			(28)
W	1919	Kahlbaum, Tl-1916-VIII.....		W <sub>0.1</sub> (ex)***		27.85	24.62	3.07	0.168	(139, 157, 159)
W	1919	Kahlbaum, Tl-1916-IX.....		W <sub>0.1</sub> (ex)		27.76*	24.54*	2.99*	0.084*	(139, 157, 159)
W	1919	Siemens and Halske, W <sub>1</sub> .....		Fil <sub>0.1</sub>	2500°	19.4*	15.63*			(78, 83)
W	1921	Pintsch, W <sub>11</sub> .....	Th	W(crl)		28.1	24.58			(78)
Zn	1913	Pirani.....		W		19.42	15.64			(69)
Zn	1919; 20	Kahlbaum.....	<0.01 %	W(ex)			21.48	1.56		(146, 147)
Zn	1924; 26	Kahlbaum, Zn-1921-I.....	<0.01 %	W	200°	25.8	22.00	1.05		(78, 79, 83)
Zr	1908	de Haën.....	tr. C	W <sub>0.1</sub> (cd)	†††	25.96*	22.16*	1.37*	0.656*	(157, 159, 160)
Zr	1924	Philips Lamp Works, Zr <sub>1</sub> .....	0.1 %	B		56 <sub>0</sub>	76 <sub>0</sub>			(93, 94)
Zr	1925	Philips Lamp Works, Zr <sub>2</sub> .....	0.1 %	□B <sub>0.15, 0.15</sub>	2400°	77.90	76.56			(20)
Zr	1925	Philips Lamp Works, Zr <sub>3</sub> .....	0.12 % W	□B <sub>0.15, 0.15</sub>	2400°	76.22	74.81			(20)
Zr	1925	Philips Lamp Works, Zr <sub>4</sub> .....	0.03 % W	S(FW)M	No	26.2*	22.9*			(21)
Zr	1925	Philips Lamp Works, Zr <sub>5</sub> .....		W(crl)M	1600°	26.9	23.6			(21)

\* Given in Table 1 or 2. † Most favorable annealing temperature is near this.  
 ‡ Pure minting Au. § Successively glow and immersed in liquid air several times. || Plate was not in contact with liquid H. ¶ Annealed, unwound, re-wound but not reannealed. \*\* Wound on glass cylinder while hot.

†† Wound on mica cross. ‡‡ Wire enclosed in sealed glass tube. §§ And immersed in liquid H. ||| Crystal split parallel to base; current passes ⊥ to c-axis. ¶¶ Circular plate 1.88 mm thick, 10 mm diameter, cast in a steel mold.  
 \*\*\* Specimen has a joint. ††† Heated: 150 to 200°C, and hammered.

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 25-28, 78, 79, 83, 89, 90, 99, 100, 102, 104, 105, 110, 113, 116, 119, 120, 124, 131,  
 133, 134, 137, 146, 147, 167); Bi (2, 4, 10, 11, 22, 23, 30, 31, 33, 39, 41, 78, 83,  
 124, 133-135); C (22, 27, 92, 111, 134, 135, 142, 145); Cd (28, 37, 47-49, 78, 79,  
 82, 83, 95, 137, 146, 147, 149, 157, 159, 160); Co (80, 146, 147); Cs (9, 52-54, 57);  
 Cu (3, 4, 15, 25-28, 65, 69, 78, 79, 83, 90, 95, 101, 102, 110, 123, 124, 127, 146,  
 147, 149, 157, 159, 160, 166); Fe (4, 15, 25, 27, 28, 58, 78, 79, 83, 95, 110, 125,  
 127, 146, 147); Ga (157, 160); Ge (8, 157, 160); Hg (1, 15, 22, 23, 32, 42, 50,  
 51, 56, 113, 114, 115, 117, 125, 132, 134, 137, 152, 156, 167); In (157-159); Ir  
 (13, 78, 83); K (9, 25, 52-54, 57, 164, 165); Li (9, 52, 54, 103, 133); Mg (15, 28,  
 110); Mo (78, 83); Na (9, 52-54, 57, 165); Ni (4, 10, 26, 27, 28, 40, 59, 78, 80,  
 83, 95, 110, 125, 135, 146, 147); Pb (22, 23, 28, 62, 63, 65, 69, 78, 79, 83, 90, 95,  
 102, 104, 105, 108, 110, 115, 121, 126, 133-135, 140, 146, 147, 149, 157, 159,  
 160); Pd (3, 4, 26, 28, 78, 79, 83, 124); Pt (6, 7, 15, 17-19, 22-29, 34, 35, 62-79,  
 83-85, 91, 97, 98, 100, 102, 106, 108, 110, 112, 116, 119, 120, 125-130, 132, 134-  
 136, 146, 148, 150, 155, 157, 159-161, 167); Rb (9, 52-54, 57); Rh (13, 78, 83);  
 Sb (37, 41, 55); Si (93, 94); Sn (14, 15, 27, 28, 56, 95, 104, 105, 118, 135, 137, 152,  
 153, 157, 159, 160); Ta (78, 83, 143, 144); Te (4, 52, 54, 127); Ti (93, 94); Tl  
 (28, 139, 157, 159); W (69, 78, 83, 143); Zn (28, 47, 48, 49, 78, 79, 81, 83, 95,  
 105, 146, 147, 157, 159, 160); Zr (20, 21, 93, 94).

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ELECTRICAL RESISTIVITY OF PURE METALS AT TEMPERATURES ABOVE  $-80^{\circ}\text{C}$ 

FRANK WENNER

## CONTENTS

## MATIÈRES

## INHALTSVERZEICHNIS

## INDICE

## PAGE

Resistivity of single crystals, and its variation with temperature and pressure.	Résistivité des cristaux isolés, et sa variation avec la température et la pression.	Widerstand von Einzelkristallen und seine Änderung mit Temperatur und Druck.	Resistività di cristalli singoli e sua variazione con la temperatura e pressione.	135
Resistance of polycrystalline metals.	Résistance des métaux polycristallins.	Widerstand polykristalliner Metalle.	Resistenza di metalli policristallini.	136
Effect of hydrostatic pressure.	Effet de la pression hydrostatique.	Einfluss des hydrostatischen Druckes.	Effetto della pressione idrostatica.	136
Effect of tension.	Effet de la tension.	Einfluss der Spannung.	Effetto della tensione.	137
Effect of impurities.	Effet des impuretés.	Einfluss von Verunreinigungen.	Effetto delle impurezze.	138

TABLE 1.—ELECTRICAL RESISTIVITY ( $\rho$ ) OF SINGLE CRYSTALS OF METALS BETWEEN 0 AND  $100^{\circ}\text{C}$ , AND THE EFFECT OF PRESSURE (13)

$\rho_t = \rho_{t'}[1 + \alpha(10)^{-3}(t - t')]$ . If  $R_0$  = resistance of a given crystal at  $0^{\circ}\text{C}$  and 1 atm.,  $\frac{1}{R_0} \frac{\partial R_0}{\partial P} = a(10)^{-6}$ .  $\parallel$ ,  $\perp$  indicate the direction of the current with reference to the crystallographic  $c$ -axis.  $t$ ,  $t'$  = centigrade temperature,  $^{\circ}\text{C}$ . Unit of  $\rho = 10^{-6}$  ohm cm; of  $P = 1 \text{ kg/cm}^2 = 14.22 \text{ lb./in.}^2 = 0.968 \text{ A}_2$ .

TABLE 1.—(Continued)

	$t'$	$\rho_{t'}$	$\alpha$	$a$		$t'$	$\rho_{t'}$	$\alpha$	$a$
Bi $\parallel$	20	138	4.09	+24.5	Sb $\parallel$	20	35.6	5.32	+17.2
$\perp$	20	109	4.09	+7.5	$\perp$	20	42.6	4.64	+1.05
C* $\perp$	0	39	2.7		Sn $\parallel$	20	14.3	4.10	-10.96
		60.2			$\perp$	20	9.9	4.29	-10.28
Cd $\parallel$	20	8.30	3.94	-13.1	W	20	5.48		
$\perp$	20	6.80		-8.7	Zn $\parallel$	20	6.13	3.87	-10.87
Cu* $\perp$	20	1.5106			$\perp$	20	5.91	3.86	-6.55
Mo* $\perp$	0	5.03	4.73						

\* Source of data: C, graphite (70); Cu (20); Mo (35).



TABLE 2.—ELECTRICAL RESISTANCE OF PURE METALS AT TEMPERATURES ABOVE  $-80^{\circ}\text{C}$ : POLYCRYSTALLINE METALS

$r_t$  for a liquid = resistivity ( $\rho_t$ ) at temperature,  $t$ .

$r_t$  for a solid = resistance at temperature,  $t$ , of a specimen which at room temperature ( $t_R$ ) has a length (in direction of current) = 1 cm, and a uniform transverse sectional area = 1 cm<sup>2</sup>. If the coefficient of linear thermal expansion is  $\alpha$ ,  $\rho_t = r_t[1 + \alpha(t - t_R)]$ , the unit of  $\rho$  being 1 ohm cm if the unit of  $r$  is 1 ohm;  $r_t$  is frequently called the resistivity; it would be better to call it the apparent resistivity.

$r_t = r_t[1 + \alpha(t - t')(10)^{-3} + \beta(t - t')^2(10)^{-6}]$  if  $t_1 \leq t \leq t_2$

(A) = aged = seasoned; (an) = annealed, (av) = average, or mean value, com = commercial, cp = "chemically pure," (dr) = drawn, elec = electrolytic, fil = filament of incandescent electric lamp, graph = graphite, (hd) = hard drawn, IACS = International Annealed Copper Standard, Kb = material obtained from Kahlbaum,  $l$  = liquid, MS = Matthiessen standard, p = pure, pp = very pure, R = room temperature,  $s$  = solid,  $w$  = wire.

*Example:* What is the apparent resistivity of annealed commercial conductivity copper at  $700^{\circ}\text{C}$ ? From the table we find  $r_{t'} = 1.72$ ,  $t' = 20$ ,  $\alpha = 4.1$ ,  $\beta = 0.43$ ; hence at  $20^{\circ}$  the resistivity is  $1.72 \times 10^{-6}$  ohm cm, and at  $700^{\circ}\text{C}$   $r_{700} = 1.72[1 + 0.0041 \times (700 - 20) + 0.00000043(700 - 20)^2] \times 10^{-6} = 6.86 \times 10^{-6}$  ohm cm.

Centigrade temperatures,  $^{\circ}\text{C}$ . Unit of  $r_t = 10^{-6}$  ohm.

	$t'$	$r_{t'}$	$\alpha$	$\beta$	$t_1$	$t_2$	Remarks	Lit.
Ag	20	1.622	3.61		-80	400	p	(61)
	960.5	8.4s						(67)
	1000	17.011	0.69		960.5	1340		(67)
Al	0	2.62	4.46	1.8	-80	400	Kb	(61)
	20	2.820					com(hd)	(26)
	20	2.67					(an)wpp	(26, 79)
	20		4.21		15	30	(hd)wpp	(79)
	657	20.131	0.51		657	1100		(64)
As	20	35		Sublimed				(57)
Au	0	2.19	3.65		-80	1000	p	(22, 61, 69)
	1063	30.821	0.45		1063	1500	p	(66)
Be	20	10.1						(60)
Bi	0	106.5	3.91	5.8	-80	250	elec	(24, 68)
	269	267s						(64, 68)
	269	127.51	0.428		269	750		(68)
C	0	4100	-0.536		-80	100	fil (av)	(22)
	25	4600						(40)
	0	1375	-0.287		0	1400	graph†	(40)
	1400	825	+0.174		1400	2200	graph†	(40)
Ca	0	4.27s	3.642		0	600	99.57 %	(76)
Cd	0	6.83	3.733	3.69	-80	300	(av)	(55, 68, 69, 77)
	20	7.143					pp	(60)
	321	33.771	-0.0802	0.679	321	700		(68)
Co	0	5.595	5.51	5.3	0	100	99.91 %	(28)
Cr	0	2.6		Powdered				(72)
Cs	0	18.83s	4.78		-80	25	(av)	(37, 38)
	28	36.41	3.5		28	60	(av)	(37, 38)
Cu	20	1.78	3.8		-30	100	(hd)com	(21, 81)
	20	1.72	4.1	0.43	-80	1000	(an)com	(22, 68)
	20	1.7241	3.93				IACS	(44)
	20	1.7213					MS	(21, 81)
	20	1.6925	4.0				elec	(21, 81)
	1083	10.2s						(65)
	1083	21.31	0.265		1083	1400		(68)
Fe	0	8.53	7.257	9.63	0	600	Kb	(68)
	20	9.78					99.983 %	(60)
Ga	0	53.4s	3.46		0	20		(37)
	30	27.21	2.76		30	50		(37)
Ge	0	$89 \times 10^3$	†	†	-80	100		(5)
Hg	-50	21.30s	5.84		-80	-50		(28)
	0	94.0771	0.9098	0.811	-30	300		(6, 28, 47)
	0	94.07661	0.8862	1.1057	0	30	(av)	(26, 48, 49, 74)
In	0	8.37	4.77		-10	100		(39)
Ir	0	6.08	3.67		-80	100		(17)

TABLE 2.—(Continued)

	$t'$	$r_{t'}$	$\alpha$	$\beta$	$t_1$	$t_2$	Remarks	Lit.
K	0	6.15s	5.814	15.3	-80	60		(38, 64)
	62.5	13.01	4.92		62.5	350		(6, 60)
Li	0	8.55	4.747	1.03	-80	100		(37)
Mg	0	4.27	3.88	0.74	-80	400		(61)
	20	4.461						(27)
Mn	R	82					cp	(50)
Mo	0	5.11	4.791	0.346	0	2622	pp†	(82)
	0	5.14	4.62		0	200		(82)
Na	0	4.2s	5.087	6.10	-20	90		(28, 63)
Ni	0	6.93	5.44	6.0	-80	100	elec	(33)
	20	7.236					(an)pp	(60)
	450	28.90	0.827		450	1000	elec	(42)
	1451	108.01	0.163		1451	1650		(6)
Pb	0	19.8	3.955	2.65	-80	300	(av)	(78)
	20	20.63					p	(60, 68)
	327	94.751	0.482		327	1000		(2, 23, 46)
Pd	0	10.00	3.610		-80	200	(av)	(61)
Pt	0	11.19	3.52	-0.55	-80	400		(59, 60)
	0	9.83	3.981	-0.585	-80	1000	p	(38, 31)
Rb	0	11.3s	5.53		-80	35	(av)	(81)
	50	23.151	3.73		50	100		(17)
Rh	0	4.70	4.235	-1.85	-80	100		(4)
Ru	18	10	(Only 1 significant figure)					(39)
Sb	0	39.0	4.144	6.2	-80	20	†	(46, 48)
Sn	0	10.48s	4.359	2.4	-80	230	(dr)	(6, 60, 68)
	232	47.41	0.565		232	1000	(av)	(56)
Sr	20	22.76					elec	(80)
Th	20	18.62						(48)
Ti	0	370	-3.52	14.9	-80	250	Ti - $\alpha^{**}$	(45)
	500	670	+3.38	8.0	430	580	Ti - $\beta^{**}$	(45)
	650	600	-0.89	2.2	580	780	Ti - $\gamma^{**}$	(45)
Tl	0	17.65	4.051		-80	100		(23)
U	18	60		(U + xU <sub>2</sub> C <sub>3</sub> )				(4)
W	0	5.00	5.238	0.7††	-80	3300	fil(A)	(24, 53, 83)
Zn	0	5.64s	3.468	1.16	-80	400		(3, 55)
	20	5.916s					(an)pp	(60)
	418	37.391	-0.2785	0.40	418	850		(68)
Zr	0	164	1.16	-0.631	-80	30	99.9 %	(19)

\* Furnace electrodes.

† Acheson graphite furnace electrodes.

‡  $r_t = Ae^B$ ; for Ge,  $A = 17\,766$ ,  $B = \frac{99.5438}{t + 273} + 0.004567(t + 273)$ .

§ Seasoned wire.

|| In the Callendar equation (Vol. 1, p. 54),  $t = 100 \left( \frac{R - R_0}{R_{100} - R_0} \right) = \delta \left[ \left( \frac{t}{100} - 1 \right) \frac{t}{100} \right]$ ,  $\delta = 1.49$ .

¶ Cast Sb. Above R, behavior is erratic; results discordant (6, 68).

\*\* Only two significant figures; for Ti- $\alpha$ , only one significant figure if  $t \neq 0$ .

††  $r_t = r_0[1 + \alpha(10)^{-3} + \beta(10)^{-6} + \gamma(10)^{-9}]$ ;  $\gamma = 0.062$ .

TABLE 3.—EFFECT OF HYDROSTATIC PRESSURE UPON ELECTRICAL RESISTANCE OF METALS BETWEEN 0 AND  $100^{\circ}\text{C}$

For single crystals, see Table 1

Pressure range is 0 to 12 000 kg/cm<sup>2</sup> unless another is stated.  $R_0$ ,  $R_p$  = resistance of the specimen at temperature,  $t$ , under pressure = 1 atm. (essentially 0), and =  $P$ , respectively.  $R_p = R_0(1 + a(10)^{-3}P + b(10)^{-6}P^2)$ . Literature references are enclosed in ( ), are usually in the first column, and, in general, each refers to all the data given for the metal indicated.

*Example:* A bar of Bi at  $25^{\circ}\text{C}$  and 1 atm. has a resistance of 0.01173 ohm;  $a = 16.30$ ,  $b = 4.17$ ,  $n = 10$ , hence at  $P = 8000$  kg/cm<sup>2</sup> and  $25^{\circ}\text{C}$ , this same bar would have a resistance of  $R_{8000} = 0.01173[1 + 16.3(8000)(10)^{-3} + 4.17(8000)^2(10)^{-10}] = 0.01173(1 + 0.1304 + 0.0267) = 0.01357$  ohm.  $t$  = centigrade temperature,  $^{\circ}\text{C}$ . Unit of  $P = 1$  kg/cm<sup>2</sup> = 14.22 lb./in.<sup>2</sup> = 0.968 atm.



TABLE 3.—(Continued)

<i>t</i>	<i>a</i>	<i>b</i>	<i>n</i>	<i>t</i>	<i>a</i>	<i>b</i>	<i>n</i>
<b>Ag* (7)</b>				<b>Hg† (8)</b>			
0	-3.625	2.44	11	0s	-23.35	1.975	10
25	-3.663	2.67	11	0l	-31.92†	1.038†	9
50	-3.684	2.76	11	25	-31.60	0.840	9
75	-3.681	2.69	11	50	-32.00	0.840	9
100	-3.664	2.51	11	75	-32.75	0.850	9
<b>Al* (10)</b>				100	-34.30	0.960	9
0	-4.50	3.08	11	<b>In (7)</b>			
25	-4.45	2.64	11	0	-12.11	1.58	10
50	-4.42	2.36	11	25	-12.84	1.94	10
75	-4.43	2.86	11	50	-13.54	2.28	10
100	-4.41	3.50	11	<b>Ir (11)</b>			
<b>As (8)</b>				30	-1.74		
(7)	-3.26			<b>K</b>			
<b>Au* (7)</b>				$R_p = R_0 \left[ \frac{6115 - 0.107P}{6115 + P} \right]$			
0	-3.064	1.60	11	at 0°C (14)			
25	-3.100	1.80	11	<b>Li* (8)</b>			
50	-3.112	1.81	11	0 to 100	+7.72		
75	-3.120	1.78	11	<b>Mg (8)</b>			
100	-3.115	1.64	11	0	-4.080		
<b>Bi (7)</b>				50	-4.065		
0	+16.50	4.81	10	100	-4.018		
25	+16.30	4.17	10	<b>Mo* (7)</b>			
50	+15.92	4.03	10	0	-1.327	3.45	12
75	+15.67	3.75	10	25	-1.324	3.56	12
<b>(8)†</b>				50	-1.319	3.67	12
275l	-12.9†	2.8†	10	75	-1.315	3.78	12
<b>C* (8)</b>				100	-1.312	3.89	12
0	+7.51	-2.96	10	<b>Na (8)</b>			
50	+4.01	-2.25	10	20s	-51.5	1.78	9
<b>Ca* (8)</b>				60s	-61.7	2.15	9
0	+10.28	2.19	10	100s	-65.0	2.6	9
25	+10.17	1.94	10	<b>Ni (10)</b>			
50	+9.92	1.80	10	0	-1.880	4.14	12
75	+9.33	1.94	10	25	-1.909	5.5	12
100	+9.25	1.80	10	50	-1.934	6.89	12
<b>Cd* (7)</b>				75	-1.957	8.25	12
0	-10.83	1.57	10	100	-1.975	9.64	12
25	-11.12	1.68	10	<b>Pb* (7)</b>			
50	-11.34	1.78	10	0	-14.32	1.83	10
75	-11.51	1.88	10	25	-14.72	2.08	10
100	-11.65	1.96	10	50	-15.11	2.33	10
<b>Co* (10)</b>				75	-15.52	2.57	10
30	-0.934			100	-15.92	2.82	10
<b>Cs; see Fig. 1</b>				<b>Pd (7)</b>			
<b>Cu* (7)</b>				0	-1.965	5.8	12
0	-1.972	1.17	11	25	-1.967	6.7	12
25	-1.945	1.11	11	50	-1.959	6.7	12
50	-1.916	1.00	11	75	-1.941	5.8	12
75	-1.899	0.97	11	100	-1.916	4.4	12
100	-1.872	0.86	11	<b>Pt (7)</b>			
<b>Fe* (7)</b>				0	-1.975	8.75	12
0	-2.405	1.19	11	25	-1.962	8.33	12
25	-2.440	1.29	11	50	-1.949	7.86	12
50	-2.473	1.37	11	75	-1.936	7.92	12
75	-2.505	1.46	11	100	-1.923	7.09	12
100	-2.540	1.56	11	<b>Rb</b>			
<b>Ga*† (8)</b>				$R_p = R_0 \left[ \frac{4431 + 0.1154P}{4431 + P} \right]$			
30l	-6.80	4.0	11	at 0°C (14)			
65l	-6.10	6.0	11				
100l	-5.78	2.8	11				

TABLE 3. (Continued)

<i>t</i>	<i>a</i>	<i>b</i>	<i>n</i>	<i>t</i>	<i>a</i>	<i>b</i>	<i>n</i>
<b>Rb.—(Continued)</b>				<b>Zn* (7)</b>			
$R_p = R_0 \left[ \frac{3525 + 0.1168P}{3525 + P} \right]$				0	-5.40	5.8	11
at 35°C (14)				25	-5.404	6.42	11
<b>Rh (11)</b>				50	-5.430	7.00	11
30	-1.74			75	-5.472	7.58	11
<b>Sb* (7)</b>				100	-5.524	8.17	11
0	+12.20			<b>Zr* (8)</b>			
25	+11.07			0	-0.5		
50	+9.94			0	-0.398		
75	+8.81			95	-0.396		
100	+7.68			*Purity as follows Ag = 99.97 %.			
<b>Sn* (7)</b>				Al = 99.976 % + 0.014 % Si + 0.007 %			
0	-10.40	1.00	10	Fe + 0.003 % Cu. Au = 99.97 %			
25	-10.66	1.15	10	C, for 0° = Acheson graphite; for 50°			
50	-10.92	1.30	10	= purified Acheson graphite. Ca =			
75	-11.18	1.46	10	99.9+ %. Cd is Kahlbaum's "K."			
100	-11.44	1.61	10	Co = 99.73 % + 0.14 % Fe + 0.019 %			
<b>Sr (8)</b>				S + 0.02 % Si + 0.09 % C + 0.00 %			
0	+48.93	1.59	9	Ni. Cu = 99.995+ %. Fe =			
50	+42.92	1.54	9	99.97 %. Ga = 99.99+ % + tr. Zn.			
100	+39.17	1.55	9	Li contains 0.7 % Al + tr. Fe. Mo =			
<b>Tl (7)</b>				99.8 %. Pb = 99.999+ % + tr. Cu.			
0	-13.44	1.61	10	Ag. Sb = 99.45 % + tr. As, Fe, no			
25	-13.99	1.95	10	other metals. Sn is Kahlbaum's			
50	-14.57	2.29	10	"K." W = 99.97 %. Zn is Kahl-			
75	-15.18	2.63	10	baum's "K;" tr. Cd, Fe, Pb. Zr for			
100	-15.81	2.96	10	first line contains 1.8 % W; for other			
<b>U (10)</b>				two 0.6 % W.			
30	-4.36			† Data for Ga, Hg, and liquid Bi			
<b>W* (8)</b>				have been corrected for compression of			
0	-1.346			specimen, and the recorded coefficients			
50	-1.340			refer to the resistivity of the material,			
100	-1.368			not to the resistance of the specimen.			

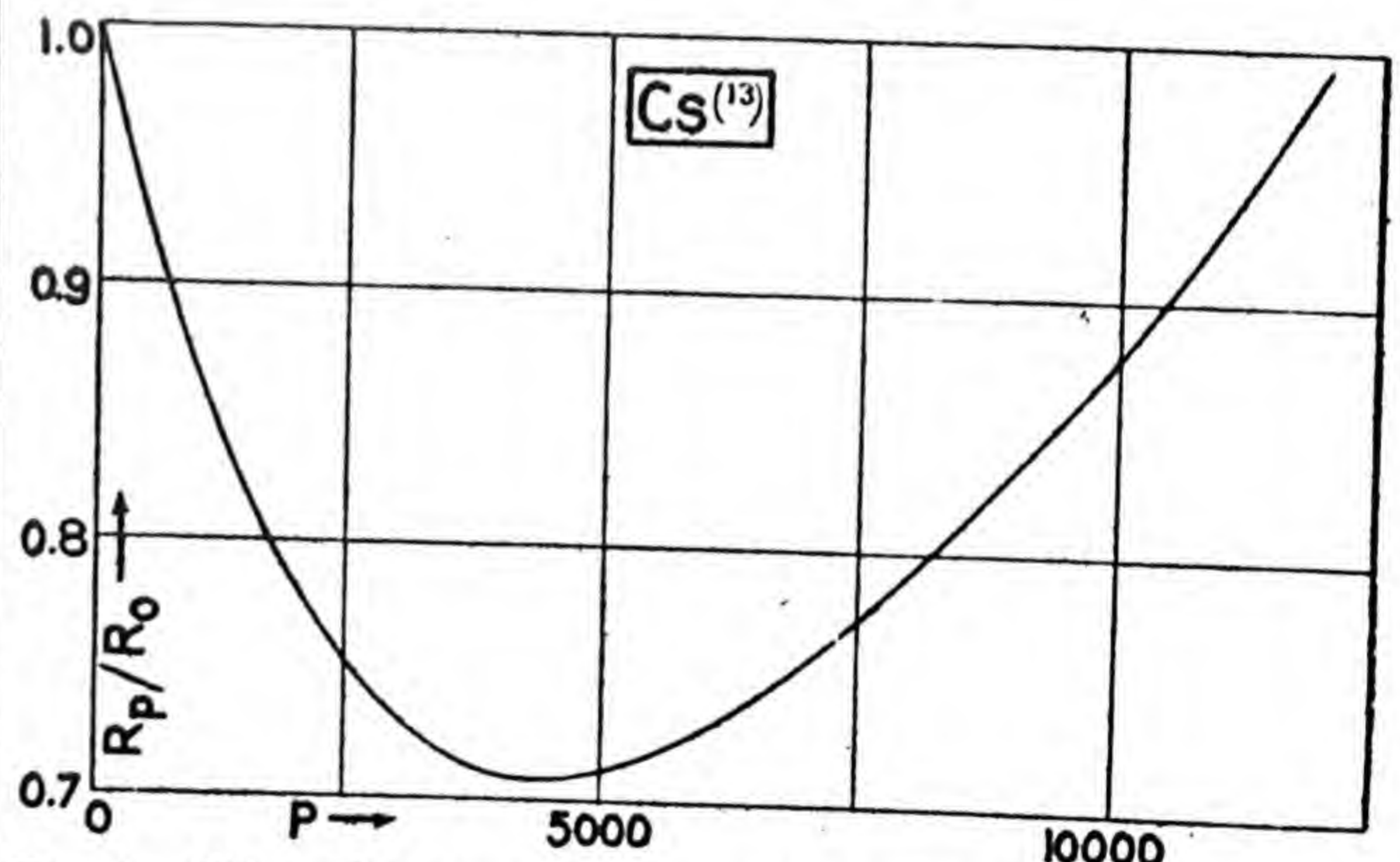
† For  $P = 7000$ .§ For  $7640 \geq P \geq 12000$ ;  $\rho_p = \rho_{7640} [1 + a(10)^{-6}(P - 7640) + b(10)^{-8}(P - 7640)^2]$ .|| For  $1000 \geq P \geq 12000$ ;  $R_p = R_{1000} [1 + a(10)^{-6}(P - 1000) + b(10)^{-8}(P - 1000)^2]$ .FIG. 1.—Effect of pressure upon electrical resistance of cesium (13).  
Unit of  $P = 1 \text{ kg/cm}^2 = 14.223 \text{ lb./in.}^2 = 0.9678 \text{ atmosphere}$ .

TABLE 4.—EFFECT OF TENSION UPON ELECTRICAL RESISTANCE OF PURE METALS (9, 12, 14)

$R_0, R_s$  = resistance of a given specimen when tension = 0, =  $S$ , respectively.  $\rho_0, \rho_s$  = resistivity of a given material when tension = 0, =  $S$ , respectively. Temperature is the same for  $R_0, \rho_0$  as for  $R_s, \rho_s$ .  $a(10)^{-6} = (R_s - R_0)/R_0 S'$ ;  $\alpha(10)^{-6} = (\rho_s - \rho_0)/\rho_0 S'$ ;  $S'$  = value of  $S$  which corresponds to tabulated values of  $\alpha$  and  $\alpha$ ;



if all values of  $S$  from 0 to  $S'$  lead to same values for  $a$  and  $\alpha$ , a † is placed after the value of  $S'$ ; in this case  $R_s = R_0(1 + a(10)^{-S})$ ,  $\rho_s = \rho_0(1 + \alpha(10)^{-S})$  if  $S \leq S'$ . Unit of  $S' = 1 \text{ kg/cm}^2 = 14.22 \text{ lb./in.}^2$

### I. Longitudinal effect, stress parallel to current

	$a$	$\alpha$	$S'$
Ag.....	5.04	2.86	250†
Al*.....	6.3	4.0	130†
Au.....	6.17	3.87	120†
Bi*.....	-29.2	-3.65	0.300†
Ca*.....	8.37	0.8	240†
Co*.....	0.994	0.19	0.100†
Cu*.....	2.66	1.3	580
	3.03	1.7	1080
Fe*.....	2.51	1.80	1025
	2.53	1.82	2050
Li.....	4.8	11	0.035†
Ni*.....	-2.53	-3.3	1900
Pd.....	3.19	1.66	457
	3.05	1.52	770
Pt*.....	2.82	1.78	400†
Sb.....	5.0	3.0	0.140†
Sr*.....	-8.3	-21.2	400†

### II. Transverse effect, stress perpendicular to current, $S' = 400$

	Purity	$\alpha$
Pd.....	99.9%	0.51
Pt.....	99.9+%	0.34

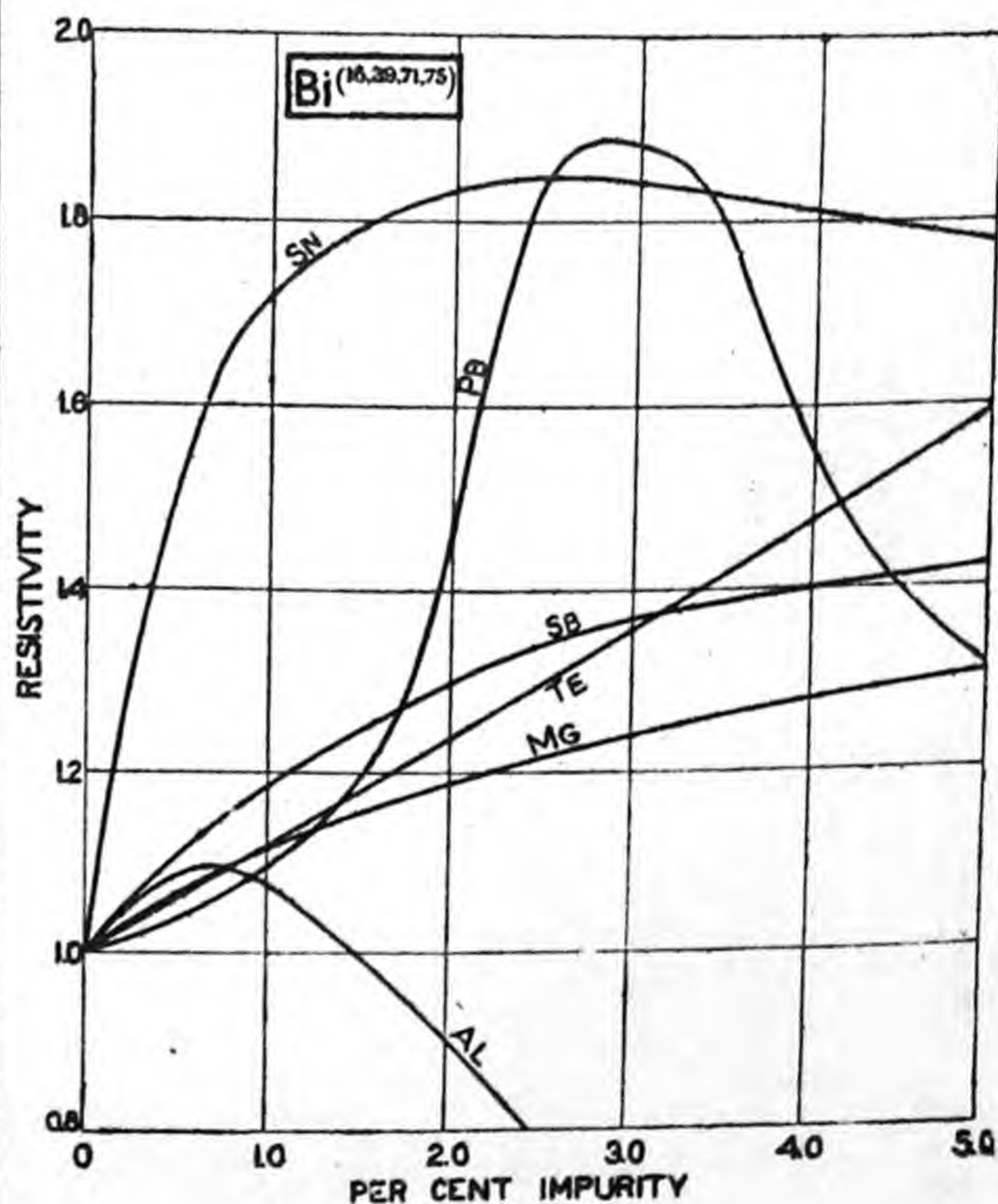
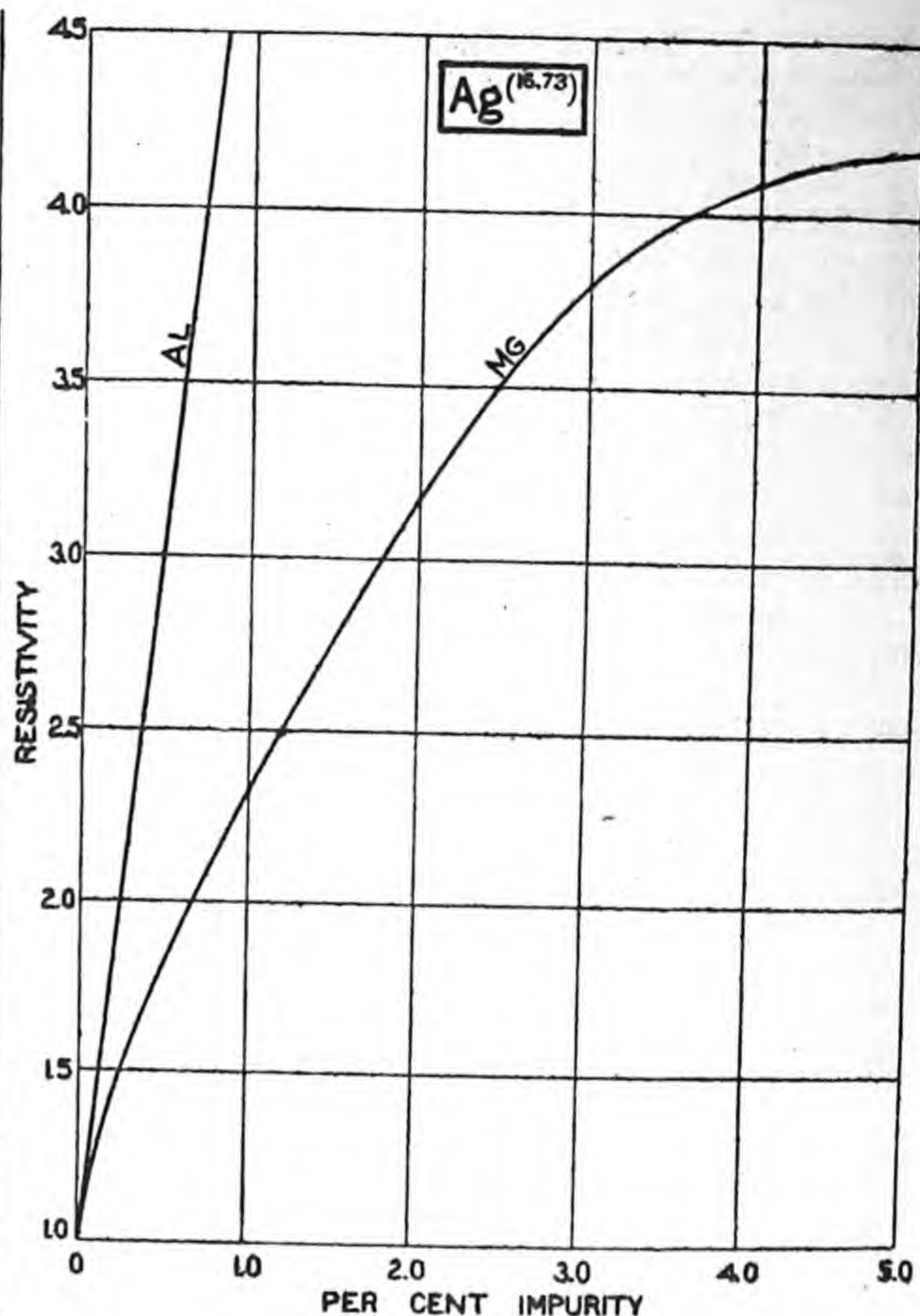
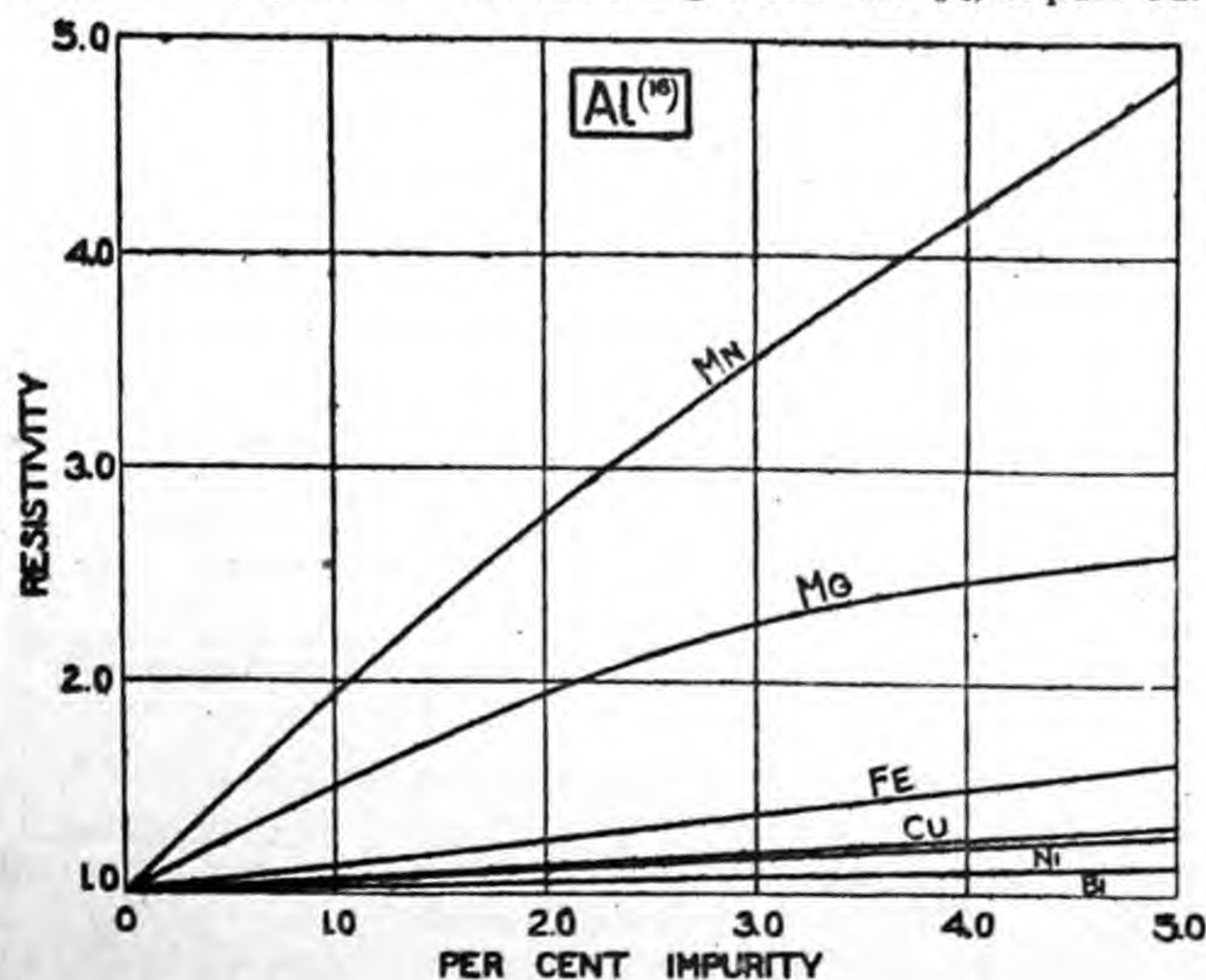
\* Purity as follows: Al > 99.97%; Au > 99.9%; Bi = 99.97% + 0.03% Ag; Ca = chemically pure; Co = 98.71% + 1.15% Fe, 0.14% Si, 0.012% S, 0.039% C; Cu > 99.995%; Fe > 99.97%; Ni > 99%; Pt > 99.9%; Sr > 98%.

† Values of  $a$  and  $\alpha$  are independent of  $S$  if  $S \leq S'$ ; for Li, if  $0.015 \leq S \leq S'$ .

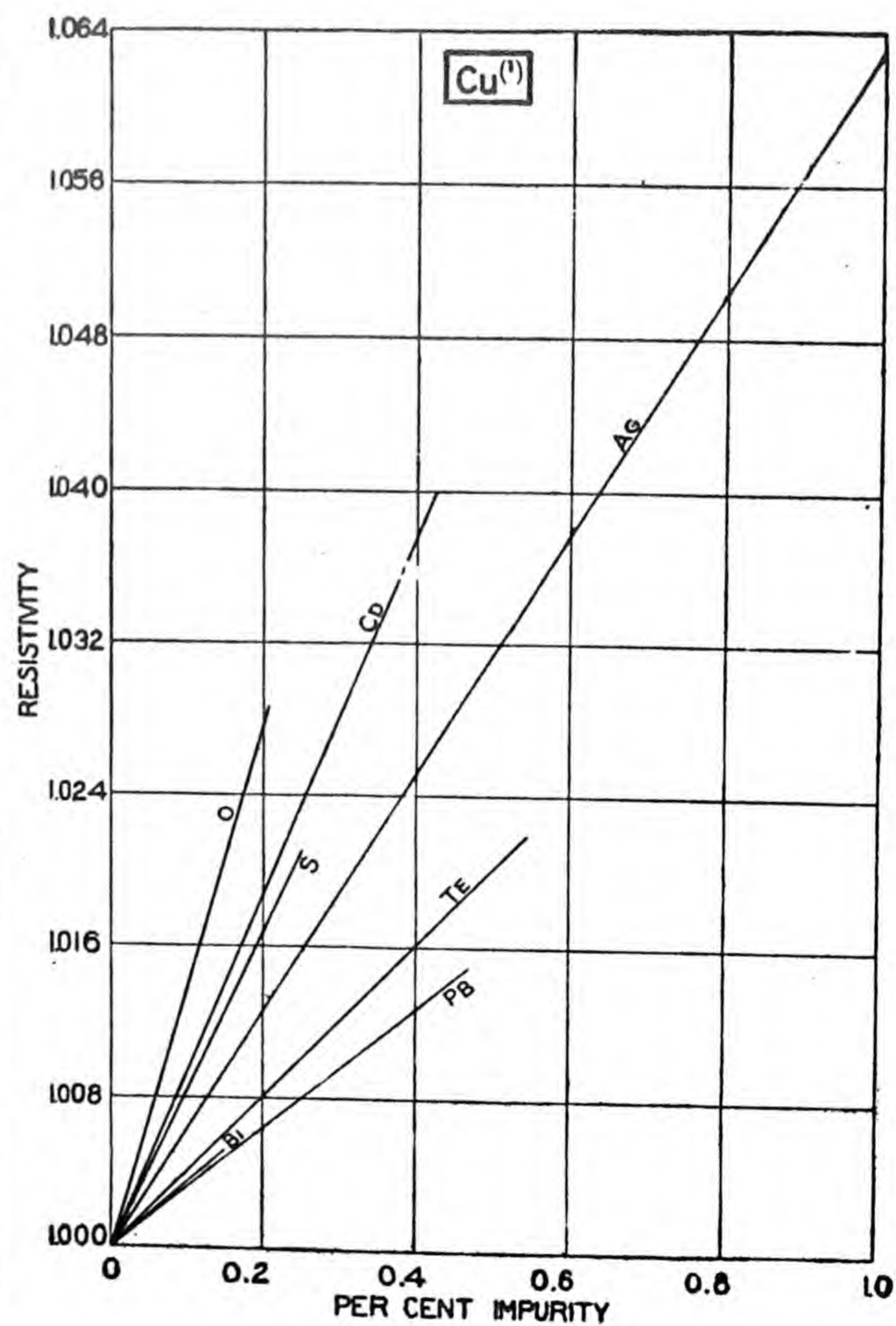
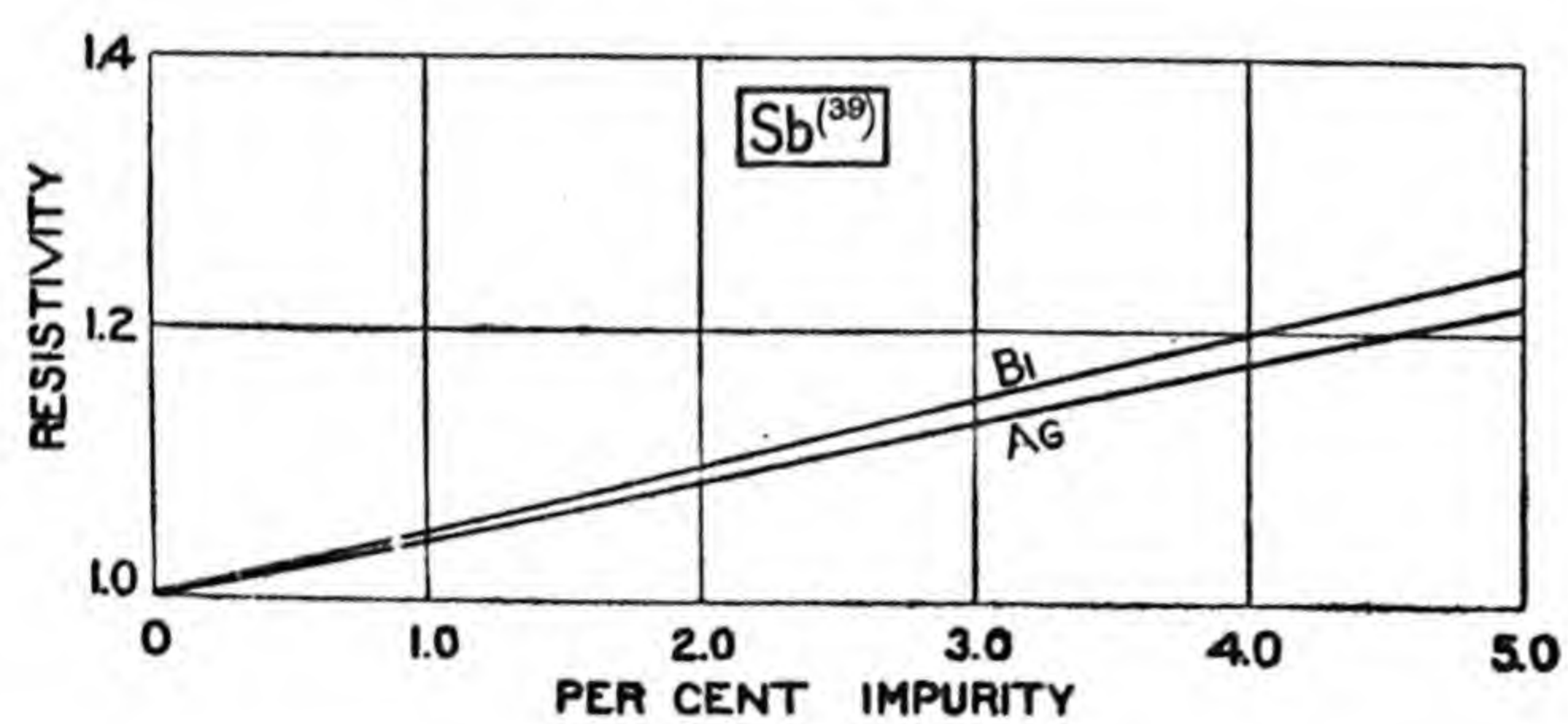
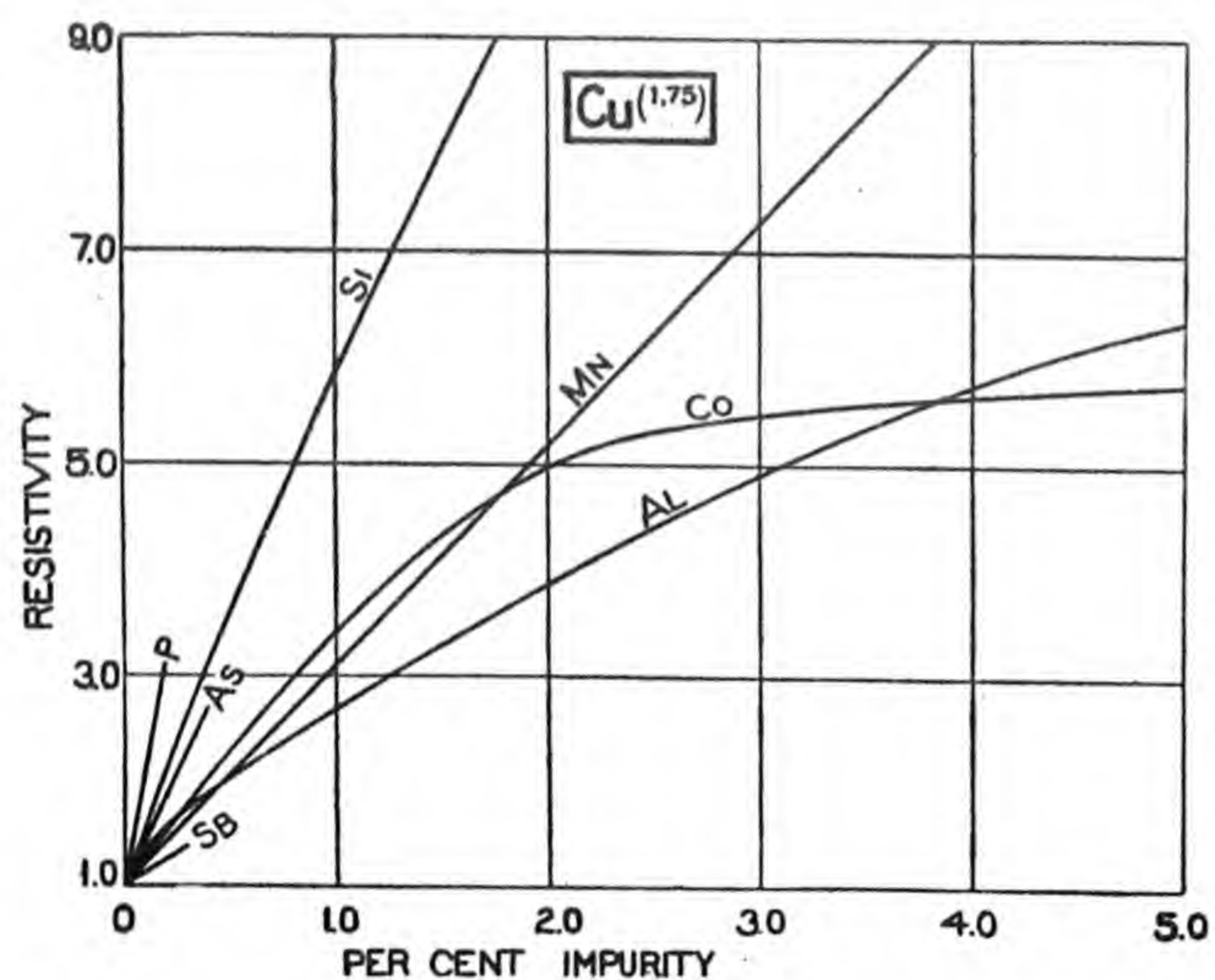
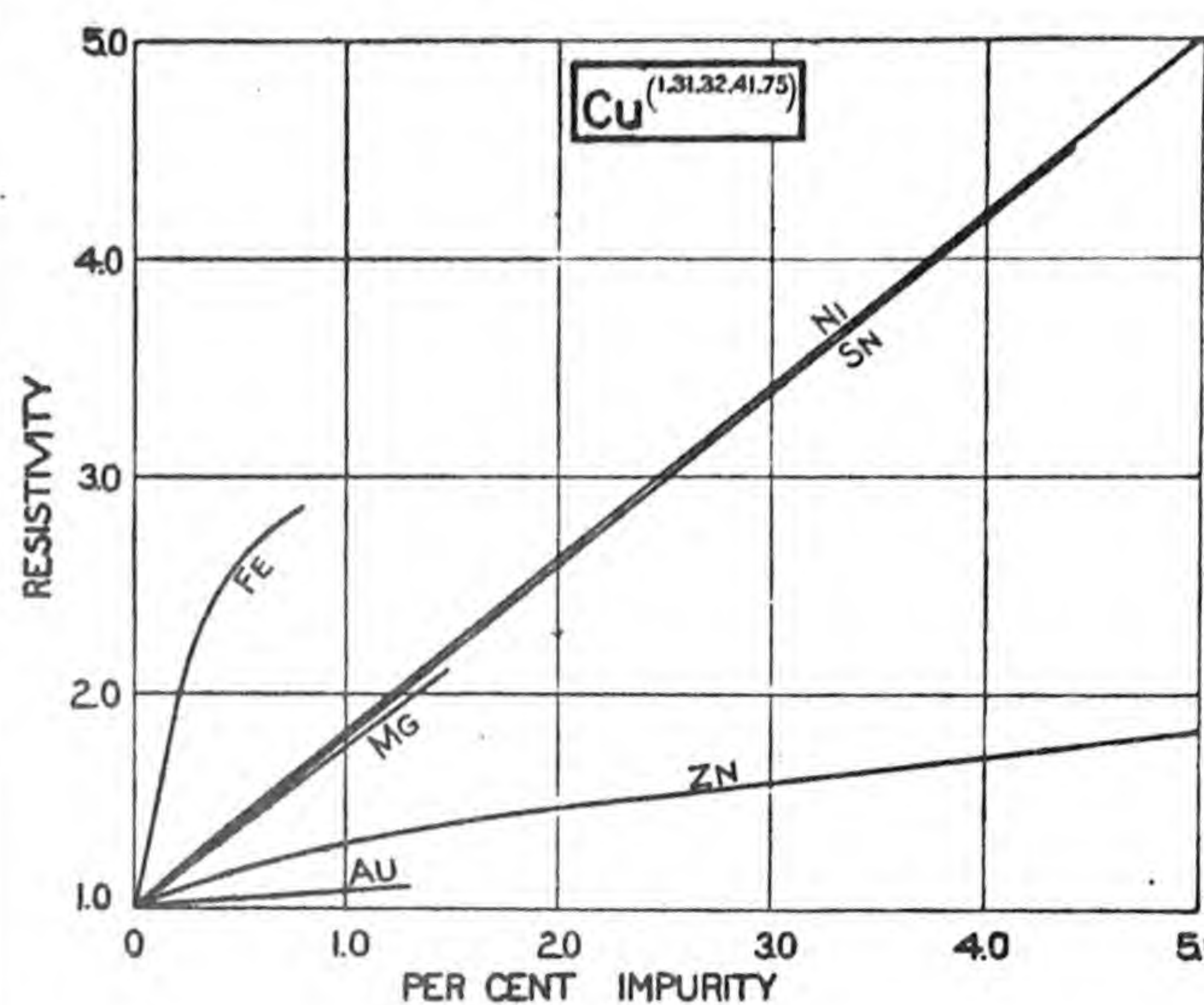
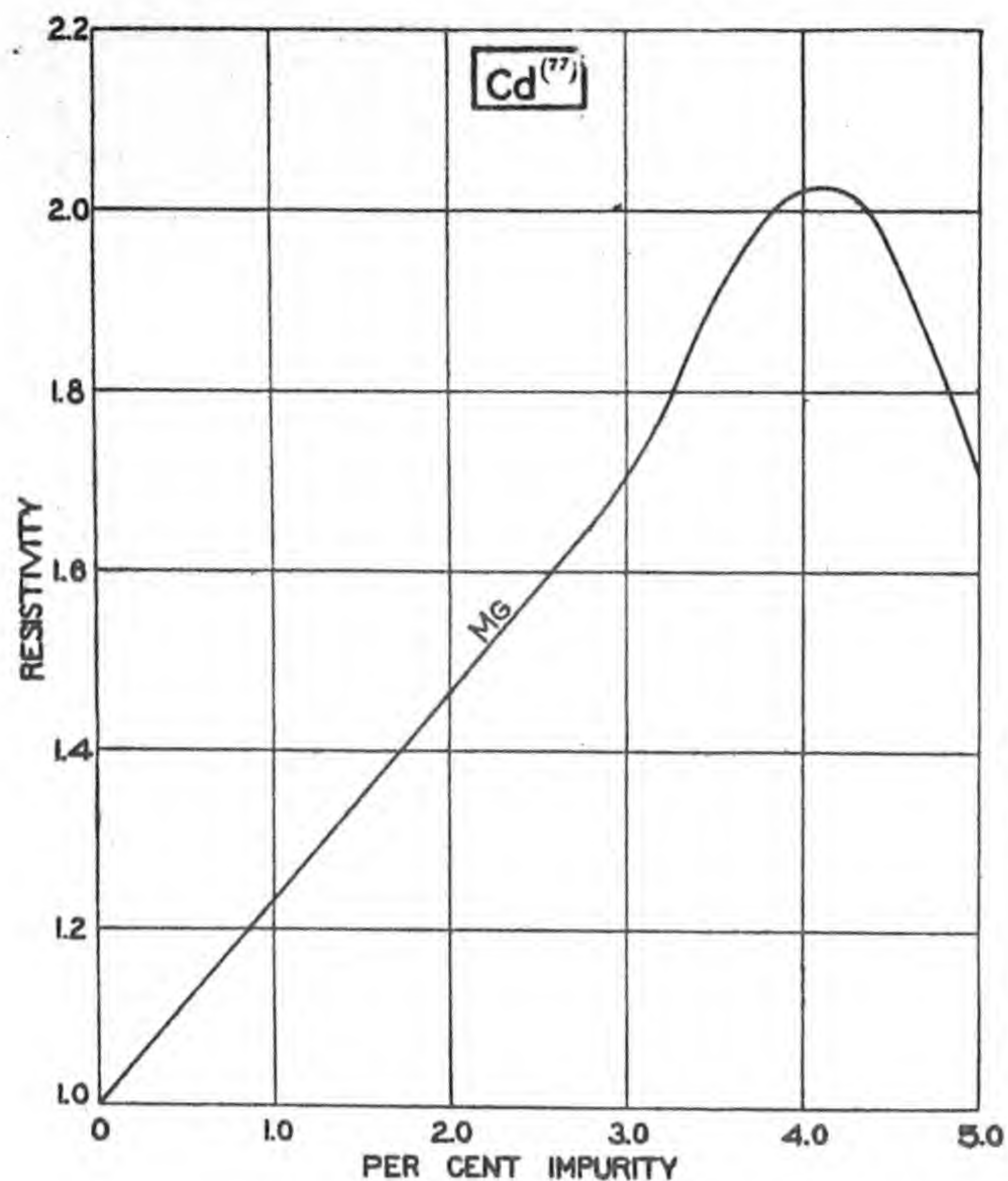
### EFFECT OF IMPURITIES UPON THE ELECTRICAL RESISTIVITY OF METALS

In each of the following figures each curve represents the variation of the resistivity of the metal named at the top of the figure with the amount of the impurity named upon the curve. The abscissae denote the per cent by weight of the impurity and the ordinates denote the values of  $\rho_i/\rho_0$  at room temperature;  $\rho_i$ ,  $\rho_0$  = the resistivity of the impure, of the pure material, respectively. Numbers in ( ) are literature references.

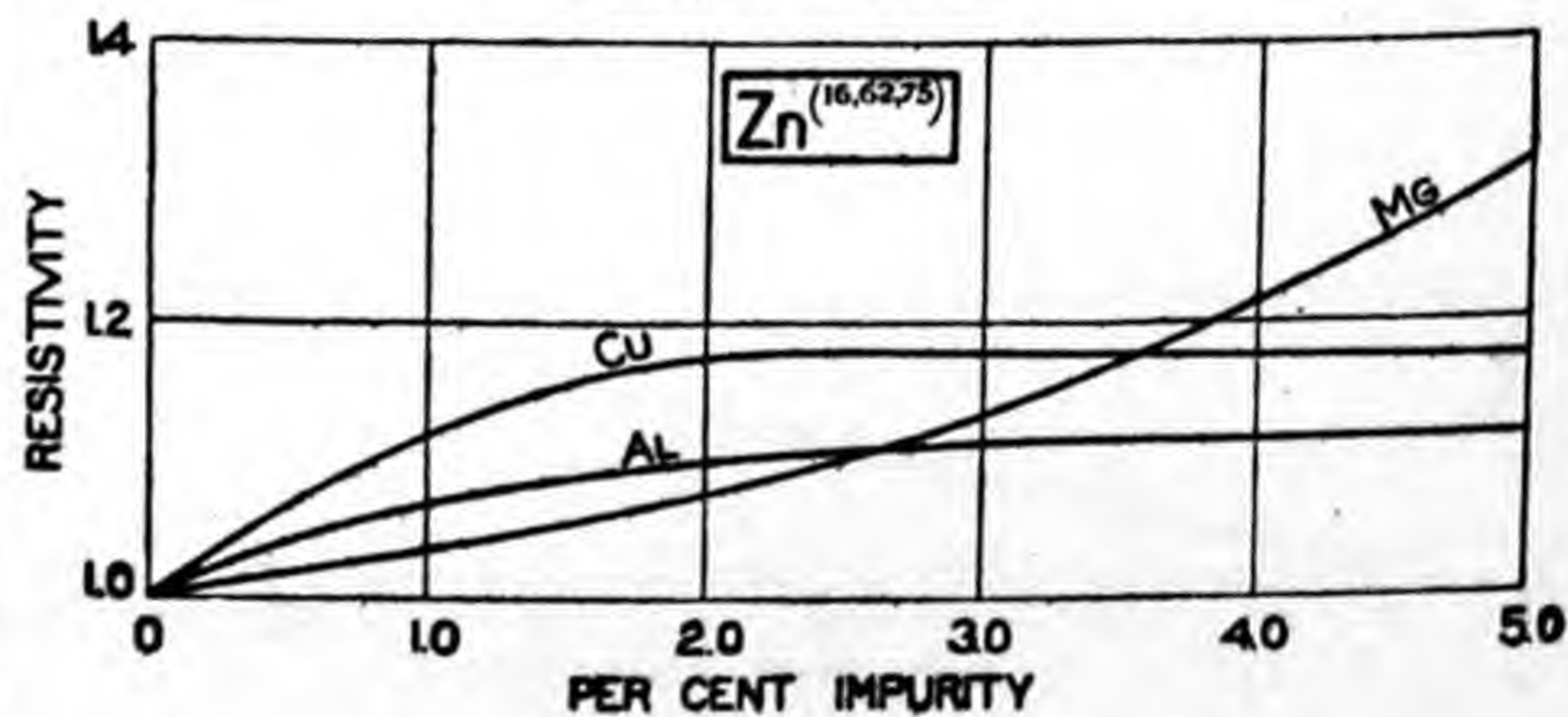
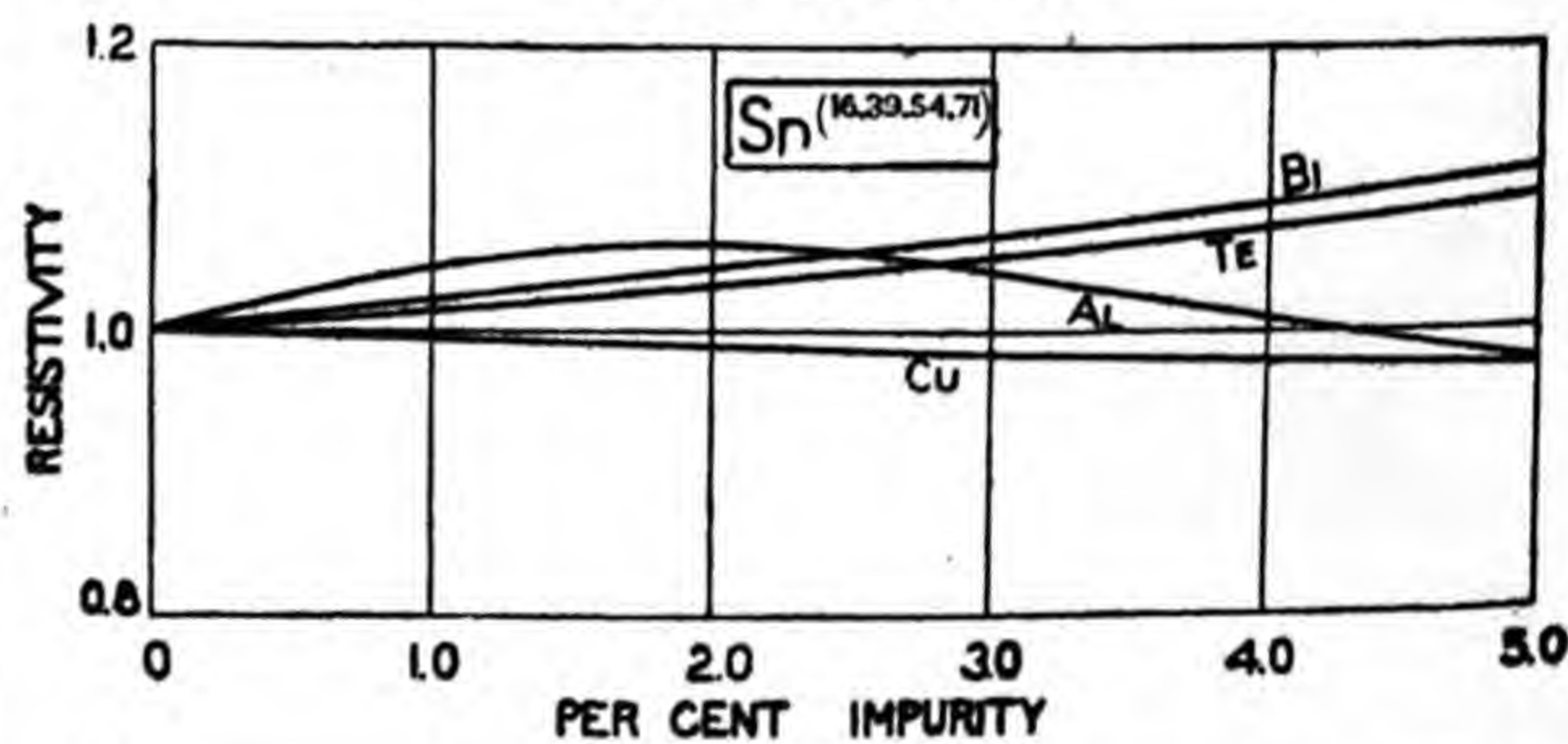
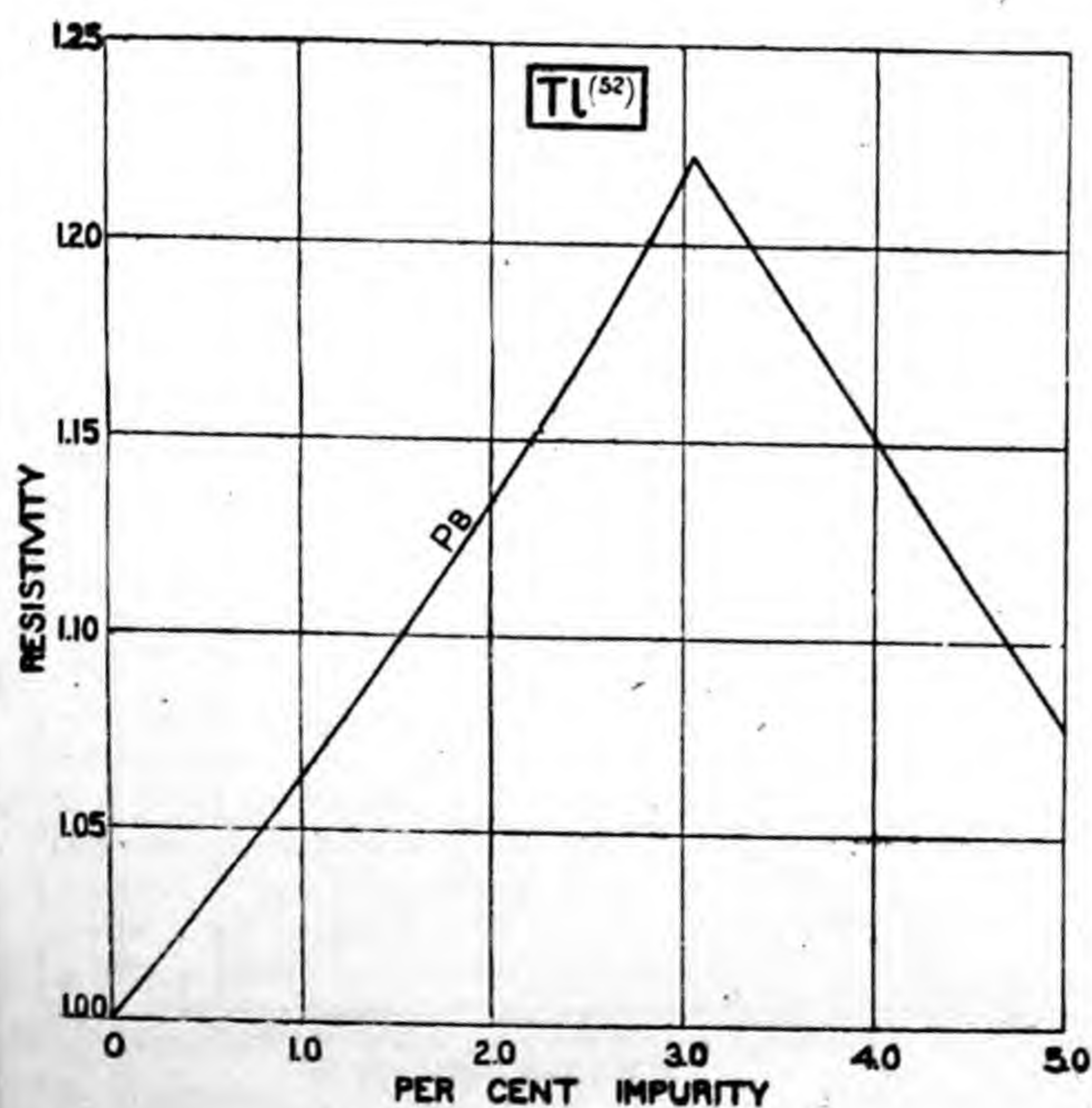
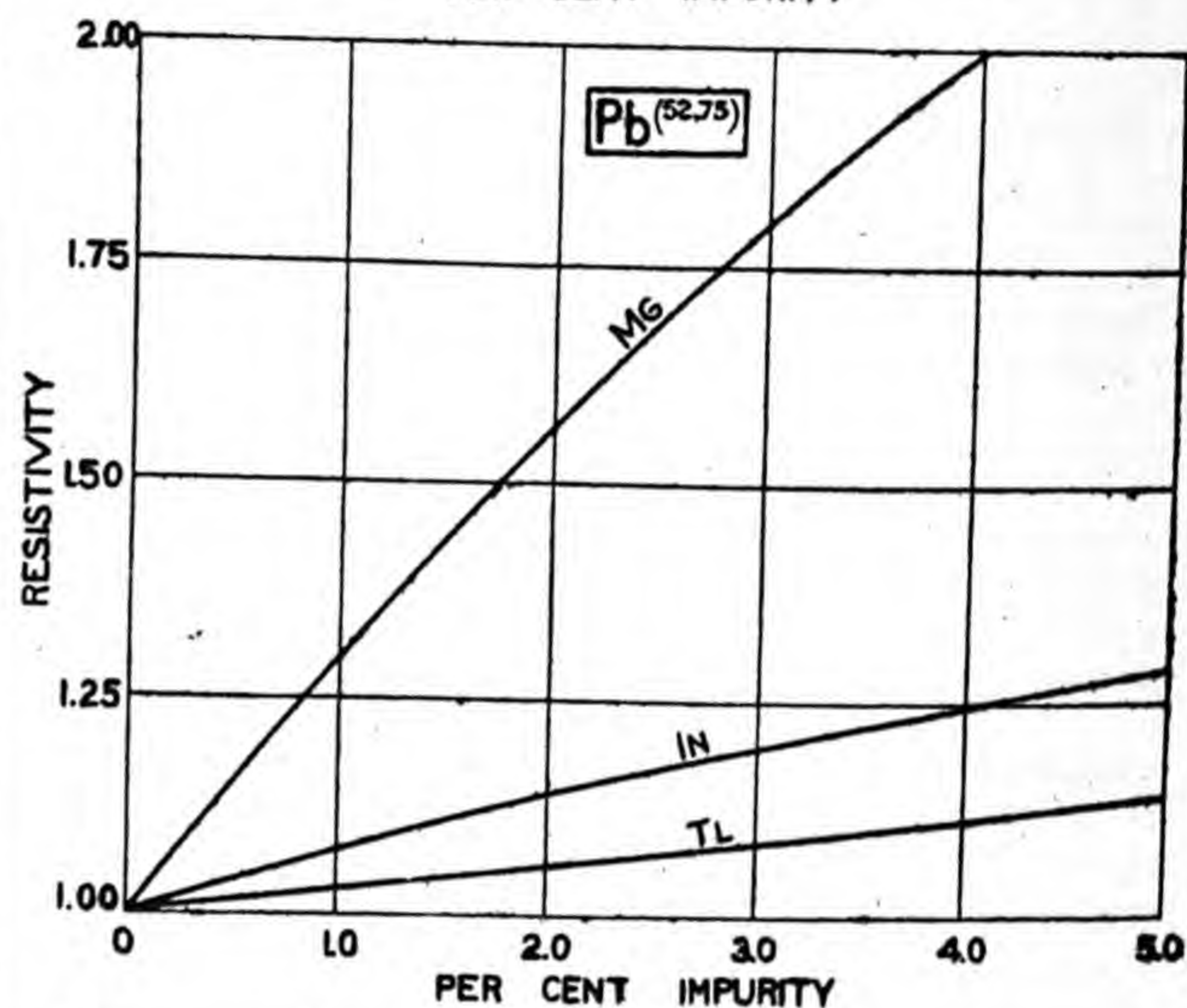
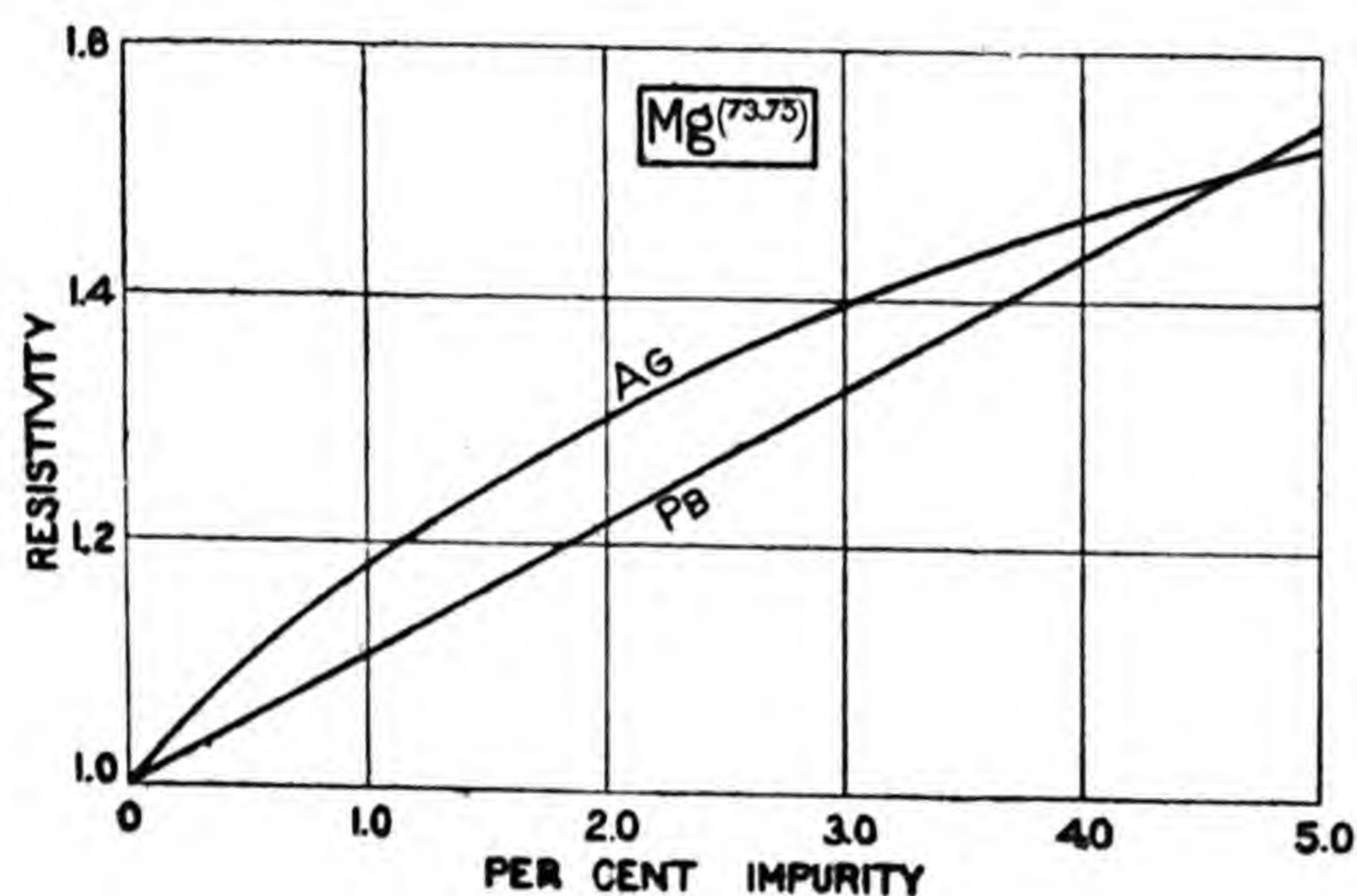
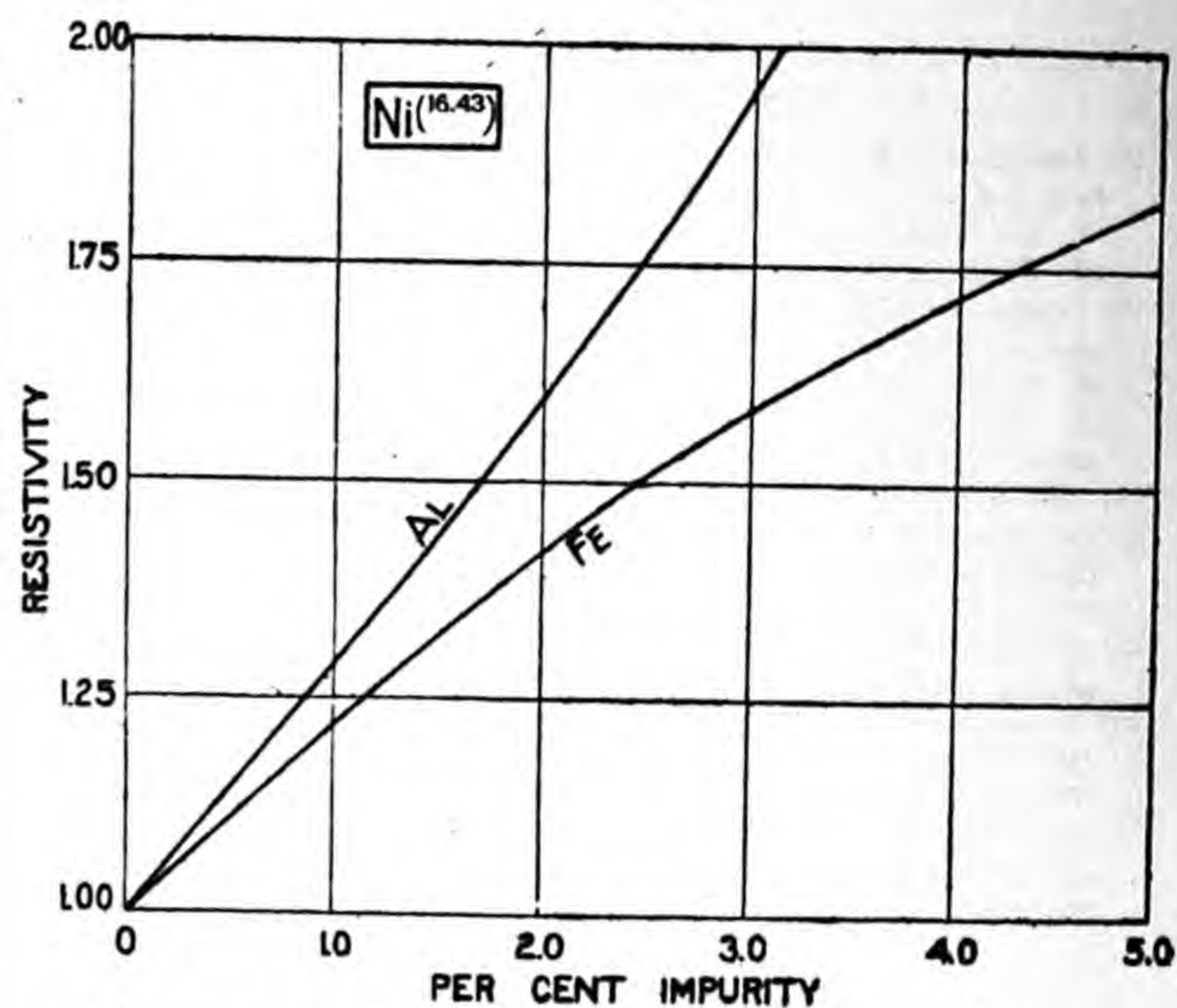
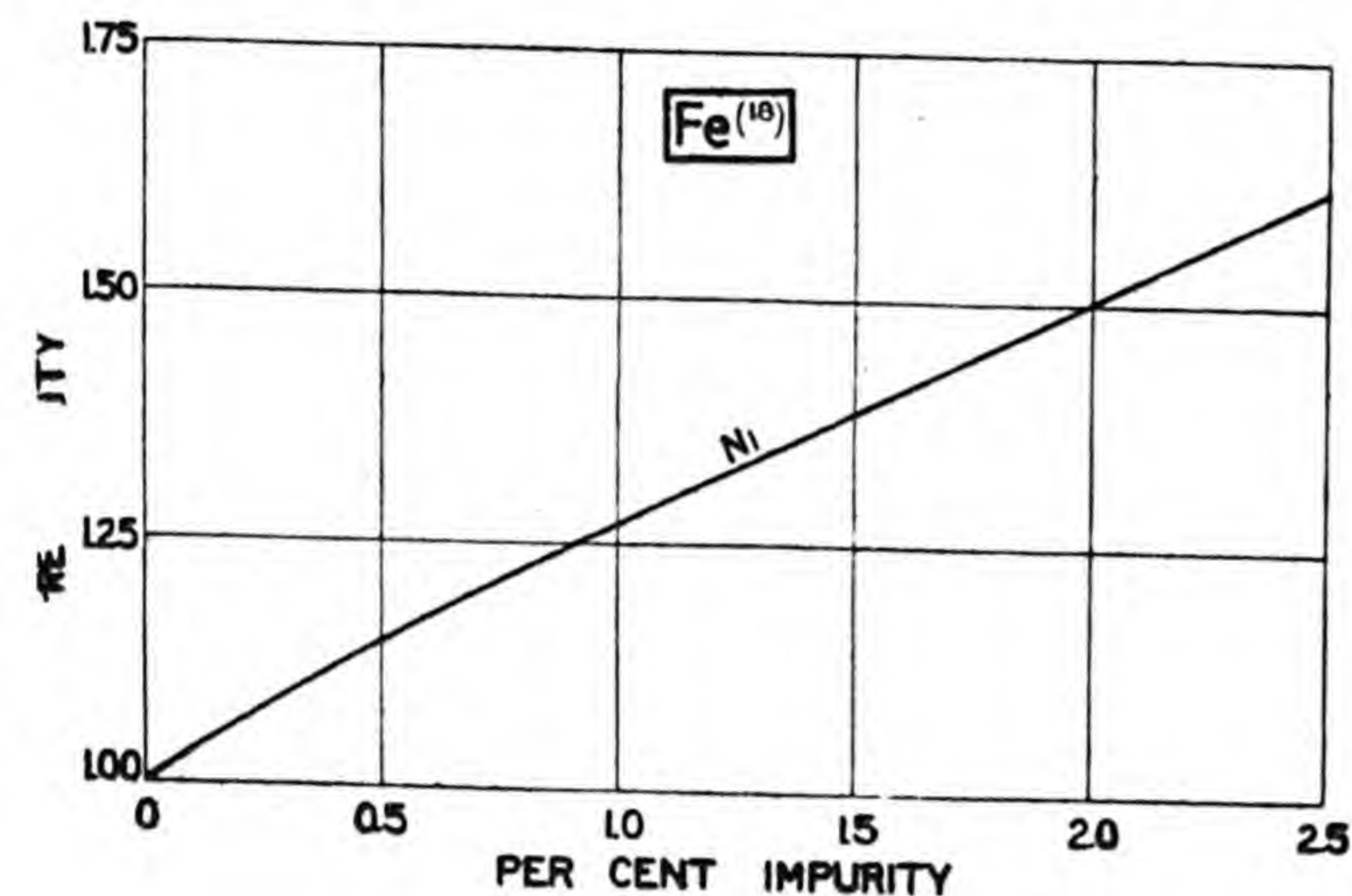
*Example:* From the curve showing the effect of Co upon the resistance of Cu, it is seen that the addition of 2.0% of Co corresponds to a relative resistivity ( $\rho_i/\rho_0$ ) of 5.0; that is the resistivity ( $\rho_i$ ) of this impure Cu is 5.0 times as great as that ( $\rho_0$ ) of pure Cu.













## LITERATURE

(For a key to the periodicals see end of volume)

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## ELECTRICAL RESISTIVITY OF S, Se, AND Te

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## CONTENTS

	PAGE
Symbols.....	141
Resistivity in the dark.....	141
Effect of light:	
Sulfur.....	141
Selenium.....	141
Tellurium.....	142

Owing to the remarkable effect of light upon Se and to the chemical analogy of Se to S and to Te, it is convenient to devote a special section to the electrical resistivities of these three substances. Not only their chemical analogies, but also the differences in their resistivities and in their response to light, may be interpreted in terms of the outer electronic structures of the atoms (17). In general the resistivity depends upon the potential gradient ( $dV/dx$ ) (1, 8); those tabulated below refer to relatively small values of the gradient.

## SYMBOLS

$I$  = intensity (energy) of illumination;  $i_t$ ,  $i_d$  = current when illuminated, when in the dark;  $P$  = pressure;  $t$  = temperature, °C;  $t_R$  = room temperature;  $V$  = applied potential;  $b$ ,  $c$ ,  $k$  = factors of proportionality;  $\lambda$  = wave-length of the illuminating radiation;  $\rho$  = resistivity.

RESISTIVITY ( $\rho$ ) IN THE DARK $P = 1 \text{ kg/cm}^2$ ;  $\rho \equiv A \times 10^7$ . Unit of  $\rho = 1 \text{ ohm-cm}$ 

Element	Form	$t$	$A$	$n$	Lit.
S.....	Orthorhombic $\alpha$	20	1.91	17	(7)
	Orthorhombic $\alpha$	30	3.90	16	(7)
	Monoclinic $\beta$	69	3.93	15	(9)
	Monoclinic $\beta$	112	7.39	12	(9)
	Liquid	130	2.0	10	(31)
	Liquid	300	2.8	8	(20)
	Liquid (see also p. 153)	440	7.7	6	(20)
Se.....	Vitreous	$t_R$	8.0	6	(27)
	Vitreous*	22	4.2	7	(18)
	Hexagonal $\perp \dagger$	20	1.0	7	(4)
	Hexagonal $\parallel \S$	24	1.93	6	(18)
	Annealed ¶	$t_R$	4.0	5	(27, 30)
	Annealed ¶	22	4.43	5	(18)

Element	Form	$t$	$A$	$n$	Lit.
Se.—(Continued).....	Liquid	390	7.66	4	(21)
	Liquid	437	2.23	4	(21)
	Liquid	540	2.24	3	(21)
	Liquid	690	8.8	1	(21)
Te.....	$\alpha \dagger$	20	2.5	-1	(14)
	$\beta$	20	5.9	-3	(14)
	$\alpha + \beta^{**}$	-200	4.9	-2	(13)
	$\alpha + \beta^{**}$	-100	6.7	-2	(13)
	$\alpha + \beta^{**}$	+ 55	1.2	-1	(13)
	$\alpha + \beta^{**}$	100	9.8	-2	(13)
	$\alpha + \beta^{**}$	200	4.7	-2	(13)
	$\alpha + \beta^{**}$	300	6.0	-3	(13)
	$\alpha + \beta^{**}$ (see also p. 129)	400	9.0	-3	(13)

\*  $P = 1.5 \text{ kg/cm}^2$ . $\dagger$  Current  $\perp$  long axis,  $P$  small; at  $P = 150 \text{ kg/cm}^2$ ,  $\rho = 10^8$ . $\ddagger \frac{1}{\rho} \frac{d\rho}{dt} = -0.63 \%$  per  $1^\circ\text{C}$ . $\S$  Current  $\parallel$  long axis,  $P = -1.05 \text{ kg/cm}^2$ ,  $\frac{1}{\rho} \frac{d\rho}{dt} = -2.57 \%$  per  $1^\circ\text{C}$ . $\P$  Annealed at  $200^\circ\text{C}$ ,  $P = 6.15 \text{ kg/cm}^2$ ;  $\frac{1}{\rho} \frac{d\rho}{dt} = -4$  to  $-6 \%$  per  $1^\circ\text{C}$  (27, 30),  $= -0.817 \%$  per  $1^\circ\text{C}$  (18). $** \frac{1}{\rho} \left( \frac{d\rho}{dp} \right)_{t=0} = -0.0129 \%$  per  $\text{kg/cm}^2$  (2).

## EFFECT OF LIGHT

**Sulfur.**—For rhombic, or  $\alpha$ -sulfur, the form stable at ordinary temperatures,  $i_t - i_d$  is very small if  $dV/dx$  is small (11); it increases with  $dV/dx$  to a limiting value at  $dV/dx$  a little greater than  $30,000 \text{ volt/cm}$ ;  $i_t - i_d = kI$ , where  $k$  is independent of  $I$  (15) but varies with  $\lambda$ , having a maximum at  $\lambda = 470 \text{ m}\mu$  ( $= 470 \times 10^{-7} \text{ cm}$ ).

**Selenium.**—Resistivity of crystalline Se is greatly reduced by illumination (28), but the decrease depends upon so many factors that it is impracticable at this time to give numerical constants of general applicability. The value of  $i_t$  depends upon the form and dimensions of the constituent crystals, upon the quality, intensity and duration of the illumination, as well as upon the temperature, pressure and applied potential difference; it varies with  $\lambda$ , passing through a well-defined maximum in the red (6, 25, 26). The variation of  $i_t$  with  $I$  is still under discussion (23); Brown (4) found  $i_t = i_d e^{bI}$ . Recently Piersol (22) confirmed the conclusion of



Rosse (24) that  $i_l - i_d = C\sqrt{I}$ , provided  $I$  is neither very small nor extremely great; here  $b$  and  $C$  are independent of  $I$  but dependent upon  $\lambda$  and other physical parameters. For dependence of  $i_l$  upon duration of illumination, see (3, 10, 16, 29); for a more complete bibliography of the entire subject, see (5, 12, 23).

#### TYPICAL DATA FOR SELENIUM BRIDGES

Annealed Bridge of the Braun Condenser Type (16). Useful area = 151 mm<sup>2</sup>; thickness = 0.1 to 0.2 mm. Unit of  $\lambda = 1\mu = 10^{-7}$  cm; of  $I_\lambda = 10^{-8}$  watt/mm<sup>2</sup>; of  $V = 1$  volt; of  $i_d$ ,  $i_l = 10^{-5}$  ampere.

$\lambda$	$I_\lambda$	$V$	$i_d$	$i_l - i_d$	$V$	$i_d$	$i_l - i_d$
451	2.83	5.60	15.7	1.09	11.03	34.9	2.23
529	4.07	5.60	15.6	1.76	11.02	34.7	3.56
674	3.68	5.35	14.7	4.26	10.70	33.8	9.78

Crystal Bridge (19). Useful area = 132 mm<sup>2</sup>; thickness = 0.2 to 0.3 mm; illumination by gas-filled tungsten (W) lamp, total unfiltered radiation;  $I = 0.5$  phot. = 0.5 lumen/cm<sup>2</sup> = 5000 m-candle = 464 ft. candle. Unit of  $V = 1$  volt; of  $i_d$ ,  $i_l = 1$  ampere.

$V$	$i_d$	$i_l - i_d$	$V$	$i_d$	$i_l - i_d$
2.0	$1.11 \times 10^{-4}$	$1.80 \times 10^{-4}$	20.0	$1.43 \times 10^{-3}$	$1.56 \times 10^{-3}$

**Tellurium.**—Some observers, neglecting effects due to the high thermoelectric power of Te with respect to other metals, have concluded that the resistivity of Te is affected by illumination. Careful investigation shows that this conclusion is incorrect (18). The absence of such an effect is in agreement with a recent interpretation of the low resistivity of Te (17).

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(For a key to the literature see end of volume)

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## THE ELECTRICAL CONDUCTIVITY OF PURE NON-METALLIC LIQUIDS<sup>1</sup>

J. R. PARTINGTON

Abbreviations.—“Non.” = a “non-conductor.”  $\kappa$  = conductivity in ohm<sup>-1</sup>cm<sup>-1</sup>.

#### Elementary Substances\* and Atmospheric Air; A-Table

Substance	$t, ^\circ\text{C}$	$\kappa = A \times 10^{-n}$		Lit.
		A	n	
Br.....	17.2	13	14	(36); cf. (122, 144); Fig. 6
Cl.....	-70(?)	<1	16	(81)
I.....	110	13	11	(36, 143); cf. Fig. 6
P.....	25	4	7	(37, 38); cf. Fig. 7
S.....	115	1	12	(37)
	130	5	11	(135)
	440	12	8	(87)
Se.....	v. p. 141			
Air.....		ca. 0		(27)
Air under Ra rays..		13	15	(27)

\* Except data below  $-80^\circ\text{C}$ , for which v. p. 124.

#### Chemical Compounds, B-Table Standard arrangement; v. Vol. III, p. viii

Substance	$t, ^\circ\text{C}$	$\kappa = A \times 10^{-n}$		Lit.
		A	n	
H <sub>2</sub> O.....	18	4	8	v. p. 152
HCl.....	-96	1	8	(2)
HBr.....	-80	8	9	(1)
HI.....	B. P.(?)	2	7	(114)
SO <sub>2</sub> ; cf. (18, 19, 31, 132, 133)	-15	9*	8	(34)
	(?)	<5	8	(13)
	35	15	8	(4)
SO <sub>3</sub> .....		“Non.”		(122)
H <sub>2</sub> S.....	B. P.(?)	1	11	(96.5); cf. (114)
H <sub>2</sub> SO <sub>4</sub> .....	25	1	2	(7); cf. (48)

<sup>1</sup> Except fused salts, for which see p. 147.

#### B-Table.—(Continued)

Substance	$t, ^\circ\text{C}$	$\kappa = A \times 10^{-n}$		Lit.
		A	n	
S <sub>2</sub> Cl <sub>2</sub> .....	25	“Non.”		(122)
SOCl <sub>2</sub> .....	25	2	6	(122)
SO <sub>2</sub> Cl <sub>2</sub> .....	25	3	8	(124)
SO <sub>2</sub> OHCl.....	25	16	5	(123)
SeOCl <sub>2</sub> .....	25	2	5	(64)
SeOBr <sub>2</sub> .....	45 to 50	6	5	(78)
NH <sub>3</sub> ; cf. (18, 19)	-33	<1	8	(39, 40)
	-79	13	8	(41)
2H <sub>3</sub> PO <sub>4</sub> .H <sub>2</sub> O.....		ca. 1	2	(97)
PCl <sub>3</sub> .....		> “Non.”		(122)
POCl <sub>3</sub> .....	25	22	7	(122)
PBr <sub>3</sub> .....		“Non.”		(122)
AsCl <sub>3</sub> .....	25	12	7	(124)
AsBr <sub>3</sub> .....	35	15	7	(123)
SbCl <sub>3</sub> .....	75(?)	85	8	(73)
SbCl <sub>5</sub> .....		“Non.”		(122)
Sb <sub>2</sub> S <sub>3</sub> .....	See Fig. 8			(75)
Carbon compounds, v. infra.				
SiCl <sub>4</sub> .....		“Non.”		(122)
Si(OCH <sub>3</sub> ) <sub>4</sub> .....	25	16	7	(84)
Si(OC <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> .....	25	<3	8	(84)
GeBr <sub>4</sub> .....	30	78	6	(30)
SnCl <sub>4</sub> .....		“Non.”		(122)
OsO <sub>4</sub> .....	40(?)	<1	11	(134.5)
Ni(CO) <sub>4</sub> .....		1	9	(85)
BCl <sub>3</sub> .....		“Non.”		(122)
B(OCH <sub>3</sub> ) <sub>3</sub> .....	0	5	6	(127)
	25	6	6	
NaOH, KOH.....	400 to 600			(3)

\* Probably high.



## Carbon Compounds; C-Table; v. Vol. III, p. viii

Natural oils at end of table; for anisotropic liquids, v. (116)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$		Lit.
			A	n	
CBrN.....	Cyanogen bromide	55	ca. 2	2	(43)
CCl <sub>4</sub> .....	Carbon tetrachloride	18	4	18	(8); cf. (55)
CCl <sub>2</sub> O.....	Carbonyl chloride	25	7	9	(42.5)
CN <sub>4</sub> O <sub>8</sub> .....	Tetranitromethane		"Non."		(127)
CS <sub>2</sub> .....	Carbon disulfide	18	73	19	(8); cf. (55, 76, 97.2)
CHBr <sub>3</sub> .....	Bromoform	25	< 2	8	(93)
CHCl <sub>3</sub> .....	Chloroform	25	< 2	8	(93); cf. (126)
CHN.....	Hydrogen cyanide	0	33	7	(129); cf. (18, 19, 22, 63)
CH <sub>2</sub> O <sub>2</sub> ; cf. (17, 91, 105, 107, 129)	Formic acid	18	56	6	(106)
		25	64	6	
CH <sub>3</sub> I.....	Methyl iodide	25	< 2	8	(93); cf. (101)
CH <sub>3</sub> NO.....	Formamide	0	18*	6	(127)
		19	18*	5	(129)
		25	4	6	(70)
CH <sub>3</sub> NO <sub>2</sub> .....	Nitromethane	0	44	8	(125)
		18	6	7	(12); cf. (26, 95)
		25	54	8	(125)
CH <sub>3</sub> NO <sub>3</sub> .....	Methyl nitrate	25	45	7	(93)
CH <sub>3</sub> O; cf. (18, 19, 60, 61, 98, 102, 115, 121)	Methyl alcohol	(?)	4	8	(51.5); cf. (62)
		18	44	8	(117)
		20	58	7	(108)
		25	22	8	(133.5); cf. (127)
CH <sub>3</sub> N.....	Methylamine		ca. 7	7	(38.5)
C <sub>2</sub> N <sub>2</sub> .....	Cyanogen		< 7	9	(22)
C <sub>2</sub> HBr <sub>3</sub> O.....	Bromal	25	8	8	(99)
C <sub>2</sub> HCl <sub>3</sub> O <sub>2</sub> .....	Trichloroacetic acid	25	3	9	(69); cf. (97.1)
		60	62	10	(70)
C <sub>2</sub> H <sub>2</sub> .....	Acetylene		"Non."		(82)
C <sub>2</sub> H <sub>3</sub> Br <sub>2</sub> O.....	Bromoacetyl bromide	0	73	8	(124)
C <sub>2</sub> H <sub>2</sub> Cl <sub>2</sub> O <sub>2</sub> .....	Dichloroacetic acid	0	4	8	(97.1)
		25	7	8	
C <sub>2</sub> H <sub>3</sub> BrO.....	Acetyl bromide	0	2	6	(127)
		25	24	7	(127)
C <sub>2</sub> H <sub>3</sub> ClO.....	Acetyl chloride	0	35	8	(127)
		25	4	7	(127)
C <sub>2</sub> H <sub>3</sub> ClO <sub>2</sub> .....	Chloroacetic acid	60	14	7	(70)
C <sub>2</sub> H <sub>3</sub> N.....	Acetonitrile	0	1	6	(125); cf. (100)
		20	7	6	(42)
		25	19	8	(127)
C <sub>2</sub> H <sub>3</sub> NO.....	Glycolic nitrile	0	52	7	(125)
		25	83	7	
C <sub>2</sub> H <sub>3</sub> NS.....	Methyl thiocyanate	0	13	7	(130); cf. (65)
		25	15	7	
C <sub>2</sub> H <sub>3</sub> NS.....	Methyl isothio-	50	3	7	(125)
	cyanate†				
C <sub>2</sub> H <sub>4</sub> Cl <sub>2</sub> .....	1, 1-Dichloroethane	25	< 17	9	(101)
C <sub>2</sub> H <sub>4</sub> Cl <sub>2</sub> .....	Ethylene chloride	25	3	8	(131)
C <sub>2</sub> H <sub>4</sub> Br <sub>2</sub> .....	Ethylene bromide	19	< 2	10	(42)
C <sub>2</sub> H <sub>4</sub> O.....	Acetaldehyde	0	14	7	(125, 127)
		15	17	7	(127)
		20.5	55	7	(42)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> ; cf. (46, 49, 58, 69, 70)	Acetic acid	0	5	9	(97.1)
		18	5*	7	(54)
		25	11.2	9	(97.1)
		30	8	9	(54)
		40	14*	8	(54)
		(?)	8	10	(14.5)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> .....	Methyl formate; see Fig. 3				
C <sub>2</sub> H <sub>4</sub> OS.....	Thioacetic acid	0	39	7	(127)
		25	27	7	
C <sub>2</sub> H <sub>5</sub> Br.....	Ethyl bromide	25	< 2	8	(93)
C <sub>2</sub> H <sub>5</sub> I.....	Ethyl iodide	25	< 2	8	(93)
C <sub>2</sub> H <sub>5</sub> NO.....	Acetamide	100	< 43	6	(134); cf. (6.5)
C <sub>2</sub> H <sub>5</sub> NO <sub>2</sub> .....	Ethyl nitrate	0	23	8	(127); cf. (101); see also Fig. 2)
		25	53	8	
C <sub>2</sub> H <sub>5</sub> O; cf. (18, 19, 26, 44, 61, 62, 63, 66, 76, 92, 117, 119, 120)	Ethyl alcohol	0	15*	8	(127)
		18	64*	9	(121)
		25	135	11	(28)

\* Probably high.

## C-Table.—(Continued)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$		Lit.
			A	n	
C <sub>2</sub> H <sub>6</sub> O <sub>2</sub> .....	Glycol	0	24	8	(127)
		25	3	7	(130)
C <sub>2</sub> H <sub>6</sub> O <sub>4</sub> S.....	Dimethyl sulfate	0	16	8	(127)
		25	3	7	
C <sub>2</sub> H <sub>6</sub> N <sub>2</sub> O.....	Dimethylnitrosamine	0	12	6	(127); cf. (129)
		25	16	6	
C <sub>2</sub> H <sub>7</sub> N.....	Ethylamine	-33.5	46	9	(35)
		0	4	7	(113)
C <sub>2</sub> H <sub>4</sub> O.....	Acrolein (not quite pure; had an acid reaction)	10	16	8	(59)
C <sub>2</sub> H <sub>5</sub> ClO.....	Epichlorohydrin	25	34	9	(127); cf. (26, 112)
C <sub>2</sub> H <sub>5</sub> ClO <sub>2</sub> .....	Ethyl chloroformate				(5)
C <sub>2</sub> H <sub>5</sub> N.....	Propionitrile	25	< 1	7	(125); see Fig. 6
C <sub>2</sub> H <sub>5</sub> NO.....	Lactonitrile(α-hydroxypropionitrile)	0	18	8	(127)
		25	31	8	
C <sub>2</sub> H <sub>5</sub> NS.....	Ethyl isothiocyanate	0	87	9	(127)
		25	126	9	
C <sub>2</sub> H <sub>5</sub> NS.....	Ethyl thiocyanate	25	12	7	(127)
C <sub>2</sub> H <sub>5</sub> Cl <sub>2</sub> O.....	Dichlorohydrin	25	12	6	(101)
C <sub>2</sub> H <sub>5</sub> O; cf. (26, 42, 112)	Acetone	-15	11	10	(130)
		0	6	8	(61)
		18	2	8	(32)
		20	12*	8	(108)
		25	6	8	(69, 70)
C <sub>2</sub> H <sub>5</sub> O.....	Allyl alcohol	25	7	6	(80)
C <sub>2</sub> H <sub>5</sub> O.....	Propionaldehyde	0	7	7	(125); cf. (26)
		25	85	8	
C <sub>2</sub> H <sub>5</sub> O <sub>2</sub> .....	Ethyl formate, see Fig. 2				
C <sub>2</sub> H <sub>5</sub> O <sub>2</sub> .....	Methyl acetate	25	34	7	(93); cf. Fig. 3
C <sub>2</sub> H <sub>5</sub> O <sub>2</sub> .....	Propionic acid	25	< 1	9	(70)
C <sub>2</sub> H <sub>5</sub> OS <sub>2</sub> .....	Ethyl xanthogenate(?)	25	< 2	8	(93)
C <sub>2</sub> H <sub>7</sub> Br.....	n-Propyl bromide	25	< 2	8	(93)
C <sub>2</sub> H <sub>7</sub> ClO <sub>2</sub> .....	Chlorohydrin	25	5	7	(101)
C <sub>2</sub> H <sub>9</sub> O.....	n-Propyl alcohol	18	5	8	(32); cf. (59, 104)
		25	2	8	(72)
		25	9	9	(11)
C <sub>2</sub> H <sub>9</sub> O.....	Isopropyl alcohol	25	35	7	(101)
C <sub>2</sub> H <sub>9</sub> O <sub>2</sub> .....	Glycerol	25	64	9	(29); cf. (20, 47, 106, 109)
C <sub>2</sub> H <sub>9</sub> N.....	Trimethylamine	-33.5	22	11	(35)
C <sub>2</sub> H <sub>9</sub> N <sub>2</sub> .....	Succinonitrile	60	15	7	(125)
C <sub>2</sub> H <sub>9</sub> Cl <sub>3</sub> O <sub>2</sub> .....	Ethyl trichloroacetate	25	3	8	(97.1); cf. (5)
C <sub>2</sub> H <sub>9</sub> NO <sub>2</sub> .....	Methyl cyanoacetate	0	3	7	(127); see Fig. 7
		25	45	8	
C <sub>2</sub> H <sub>9</sub> NS.....	Allyl isothiocyanate	25	25	6	(84); cf. (65)
C <sub>2</sub> H <sub>9</sub> Cl <sub>2</sub> O <sub>2</sub> .....	Ethyl dichloroacetate	25	7	8	(97.1); cf. (5)
C <sub>2</sub> H <sub>9</sub> O <sub>2</sub> .....	Acetic anhydride	0	1	6	(125)
		20	75*	8	(108)
		25	48	8	(127)
C <sub>2</sub> H <sub>7</sub> ClO <sub>2</sub> .....	Ethyl chloroacetate	25	2	7	(97.1); cf. (80)
C <sub>2</sub> H <sub>7</sub> N.....	n-Butyronitrile	25	12	6	(33)
C <sub>2</sub> H <sub>7</sub> Br <sub>2</sub> .....	Butylene bromide	25	< 2	8	(93)
C <sub>2</sub> H <sub>9</sub> O.....	Methyl ethyl ketone	25	1	7	(95)
C <sub>2</sub> H <sub>9</sub> O <sub>2</sub> .....	Ethyl acetate	25	< 1	9	(69, 71); cf. (101)
C <sub>2</sub> H <sub>9</sub> O <sub>2</sub> .....	Propyl formate; see Fig. 1				
C <sub>2</sub> H <sub>9</sub> O <sub>2</sub> .....	Methyl propionate; see Fig. 3				
C <sub>2</sub> H <sub>9</sub> NO <sub>2</sub> .....	Isobutyl nitrate	25	< 2	8	(93); see Fig. 1
C <sub>2</sub> H <sub>10</sub> O.....	Ether	25	< 4	13	(97.2); cf. (18, 19, 21, 42, 76, 124)
C <sub>2</sub> H <sub>10</sub> O.....	Isobutyl alcohol	18	< 1*	7	(32); cf. (101)
		25	8	8	(131)
		25	95	10	(11)
C <sub>2</sub> H <sub>10</sub> O <sub>3</sub> S.....	asym.-Diethyl sulfite	0	3	7	(127)
		25	5	7	
C <sub>2</sub> H <sub>10</sub> O <sub>3</sub> S.....	sym.-Diethyl sulfite	0	2	7	(127)
		25	4	7	
C <sub>2</sub> H <sub>10</sub> O <sub>4</sub> S.....	Diethyl sulfate	0	16	8	(127)
		25	26	8	
C <sub>2</sub> H <sub>11</sub> N.....	Diethylamine	-33.5	22	10	(35)

† In the original, the compound in question is called "methylene mustard oil," and the formula "CN.CNS" is given. The boiling point (117°) indicates, however, that the liquid is probably methyl mustard oil.



C-Table.—(Continued)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$		Lit.
			A	n	
C <sub>5</sub> H <sub>4</sub> O <sub>2</sub> .....	Furfural	0	97	8	(127)
		20	11	7	(108); cf. (101)
		25	15	7	(127)
		25	16	8	(128)
C <sub>5</sub> H <sub>4</sub> O <sub>3</sub> .....	Citraconic anhydride	0	1	7	(127)
		25	2	7	
C <sub>5</sub> H <sub>5</sub> N; cf. (51, 52, 80, 96)	Pyridine	0	57*	9	(94)
		18	53	9	(32)
		25	< 5	8	(79)
		25	68	9	(50)
C <sub>5</sub> H <sub>7</sub> NO <sub>2</sub> .....	Ethyl cyanoacetate	0	19	8	(127); cf. (80)
		25	19	8	
C <sub>5</sub> H <sub>8</sub> O <sub>2</sub> .....	Acetylacetone	0	2	7	(127)
		25	3	7	
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub> .....	Dimethyl malonate	0	8	8	(127)
		25	12	8	
C <sub>5</sub> H <sub>9</sub> N.....	Valeronitrile	25	57	7	(101)
C <sub>5</sub> H <sub>10</sub> .....	Amylene (fusel amy- lene)	25	< 2†	8	(93)
C <sub>5</sub> H <sub>10</sub> O.....	Isovaleraldehyde	0	8	8	(128)
		25	10	8	
C <sub>5</sub> H <sub>10</sub> O.....	Methyl propyl ketone	25	1	6	(80)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub> .....	Ethyl propionate; see Fig. 2				
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub> .....	Isovaleric acid	80	< 4	13	(97.2)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub> .....	Isobutyl formate; see Fig. 1				
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub> .....	Methyl butyrate; see Fig. 3				
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub> .....	Propyl acetate; see Fig. 1				
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub> .....	Diethyl carbonate	25	17	9	(101)
See also Fig. 2					
C <sub>5</sub> H <sub>11</sub> Br.....	Isoamyl bromide	25	< 2	8	(93)
C <sub>5</sub> H <sub>11</sub> I.....	Amyl iodide	25	35	7	(93)
C <sub>5</sub> H <sub>11</sub> N.....	Piperidine	25	< 2	7	(80)
C <sub>5</sub> H <sub>11</sub> NO <sub>2</sub> .....	Amyl nitrite	25	19	8	(80)
C <sub>5</sub> H <sub>11</sub> NO <sub>2</sub> .....	Amyl nitrate	25	28	8	(101); see Fig. 3
C <sub>5</sub> H <sub>12</sub> .....	Pentane	19.5	< 2	10	(42)
C <sub>5</sub> H <sub>12</sub> O.....	Isoamyl alcohol	18	5*	8	(44); cf. (42, 96)
		20	4*	8	(108)
		25	15	9	(72)
C <sub>5</sub> H <sub>12</sub> S.....	Amyl hydrogen sul- fide (amylmercaptan)	25	< 2	8	(93)
C <sub>5</sub> H <sub>12</sub> N.....	Isoamylamine	25	< 8	8	(67)
C <sub>5</sub> H <sub>5</sub> Br.....	Bromobenzene	25	< 2	11	(97.2); cf. (24, 101)
C <sub>5</sub> H <sub>5</sub> NO <sub>2</sub> ; cf. (14, 56, 86)	Nitrobenzene	0	5	9	(97.2)
		18	2*	7	(26)
		20	< 2	10	(42)
		25	< 2*	8	(93)
C <sub>6</sub> H <sub>6</sub> .....	Benzene		76	9	(18, 23, 55, 74, 76, 93, 111, 116, 126)
			< 1	18	
C <sub>6</sub> H <sub>5</sub> ClN.....	m-Chloroaniline	25	5	8	(100); cf. (131)
C <sub>6</sub> H <sub>5</sub> O.....	Phenol	25	< 17	9	(101)
C <sub>6</sub> H <sub>7</sub> N.....	Aniline	0	9†	9	(94)
		25	24	9	
		35	82	9	
C <sub>6</sub> H <sub>7</sub> N.....	Picoline	25	55	8	(101)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub> .....	Ethyl acetoacetate	25	4	8	(86); cf. (45, 131)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> .....	Diethyl oxalate	25	76	8	(80); cf. (101)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> .....	Dimethyl malate	0	3	7	(127)
		25	55	8	(126)
C <sub>6</sub> H <sub>11</sub> N.....	Capronitrile	25	37	7	(101)
C <sub>6</sub> H <sub>11</sub> NS.....	Amyl thiocyanate	25	15	6	(65)
C <sub>6</sub> H <sub>13</sub> O <sub>2</sub> .....	Amyl formate; see Fig. 3				
C <sub>6</sub> H <sub>13</sub> O <sub>2</sub> .....	Ethyl butyrate; see Fig. 2				
C <sub>6</sub> H <sub>13</sub> O <sub>2</sub> .....	Ethyl isobutyrate; see Fig. 2				
C <sub>6</sub> H <sub>13</sub> O <sub>2</sub> .....	Isobutyl acetate; see Fig. 1				
C <sub>6</sub> H <sub>13</sub> O <sub>2</sub> .....	Methyl valerate; see Fig. 3				
C <sub>6</sub> H <sub>13</sub> O <sub>2</sub> .....	Propyl propionate; see Fig. 1				
C <sub>6</sub> H <sub>13</sub> O <sub>2</sub> .....	Paraldehyde		< 36	8	(80)
C <sub>6</sub> H <sub>14</sub> .....	Hexane	18	< 1‡	18	(8); cf. (24, 56, 87, 111)
C <sub>7</sub> H <sub>5</sub> N.....	Benzonitrile	25	5	8	(131); cf. (79)

\* Probably high.

†  $\kappa = 14 \times 10^{-14}$  under the influence of radium rays; "almost a perfect insulator when shielded from the rays" (27).

‡ No noticeable change in conductivity on darkening.

§ The conductivity of the liquid decreases when enclosed by a lead mantle (111).

C-Table.—(Continued)

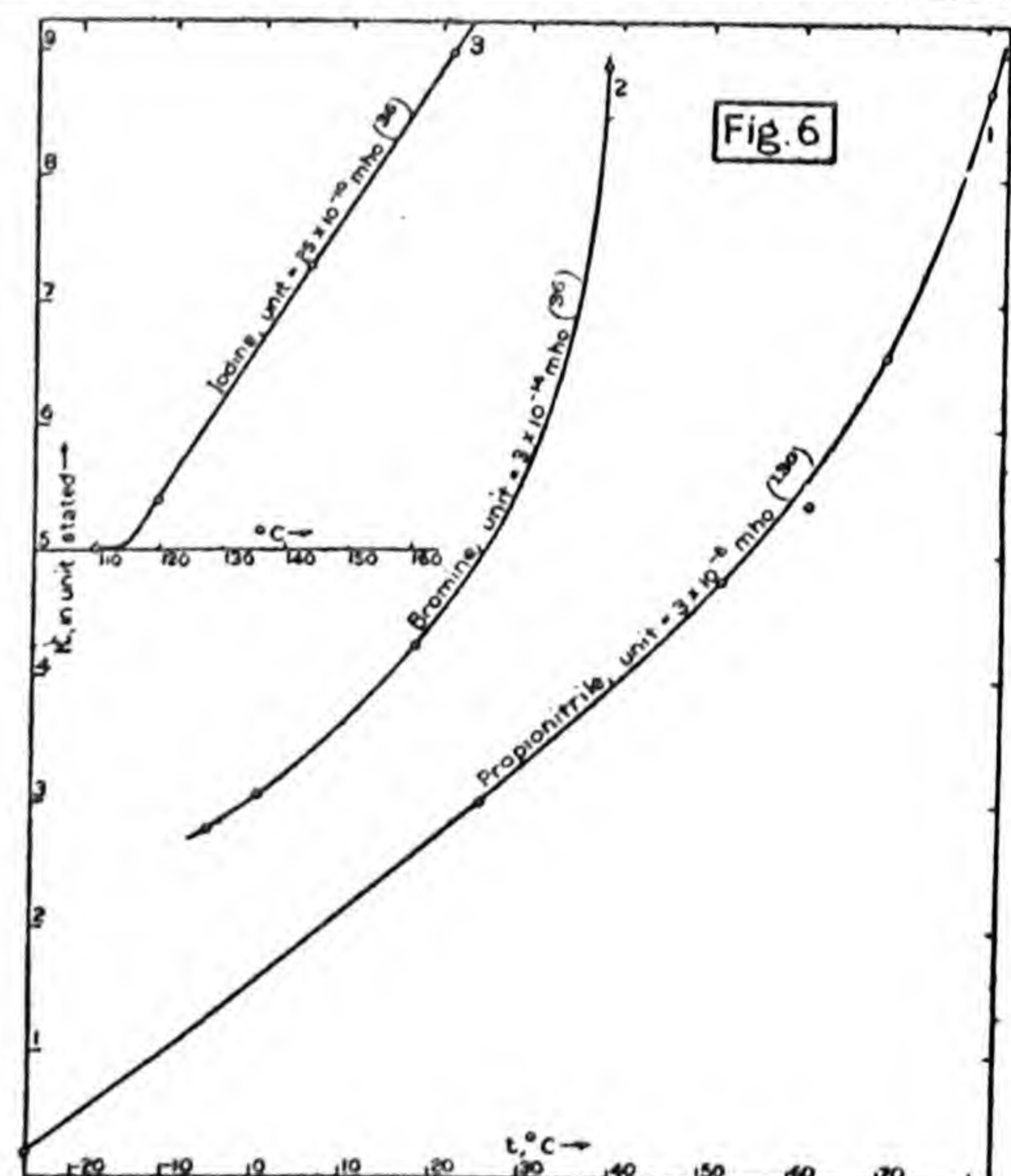
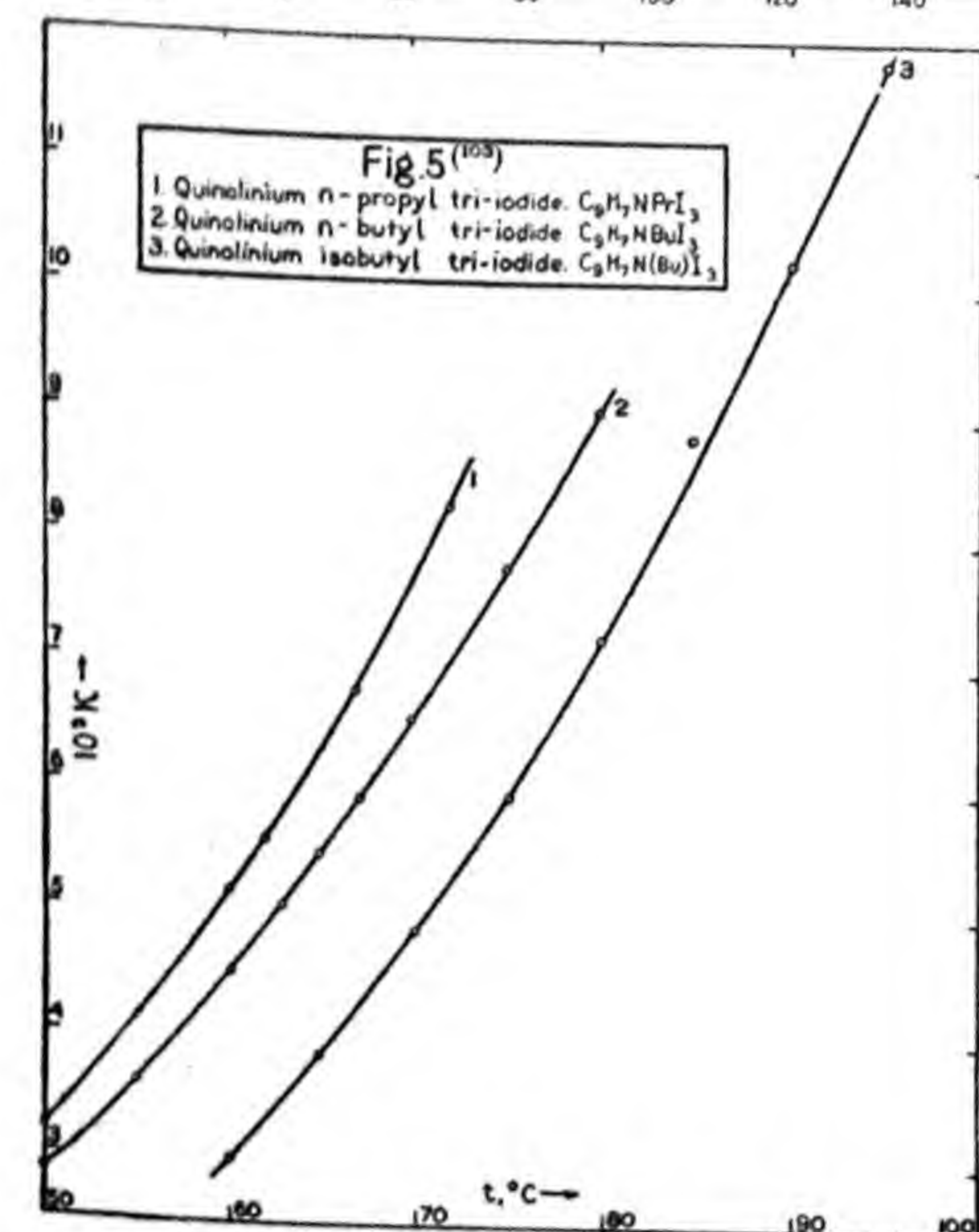
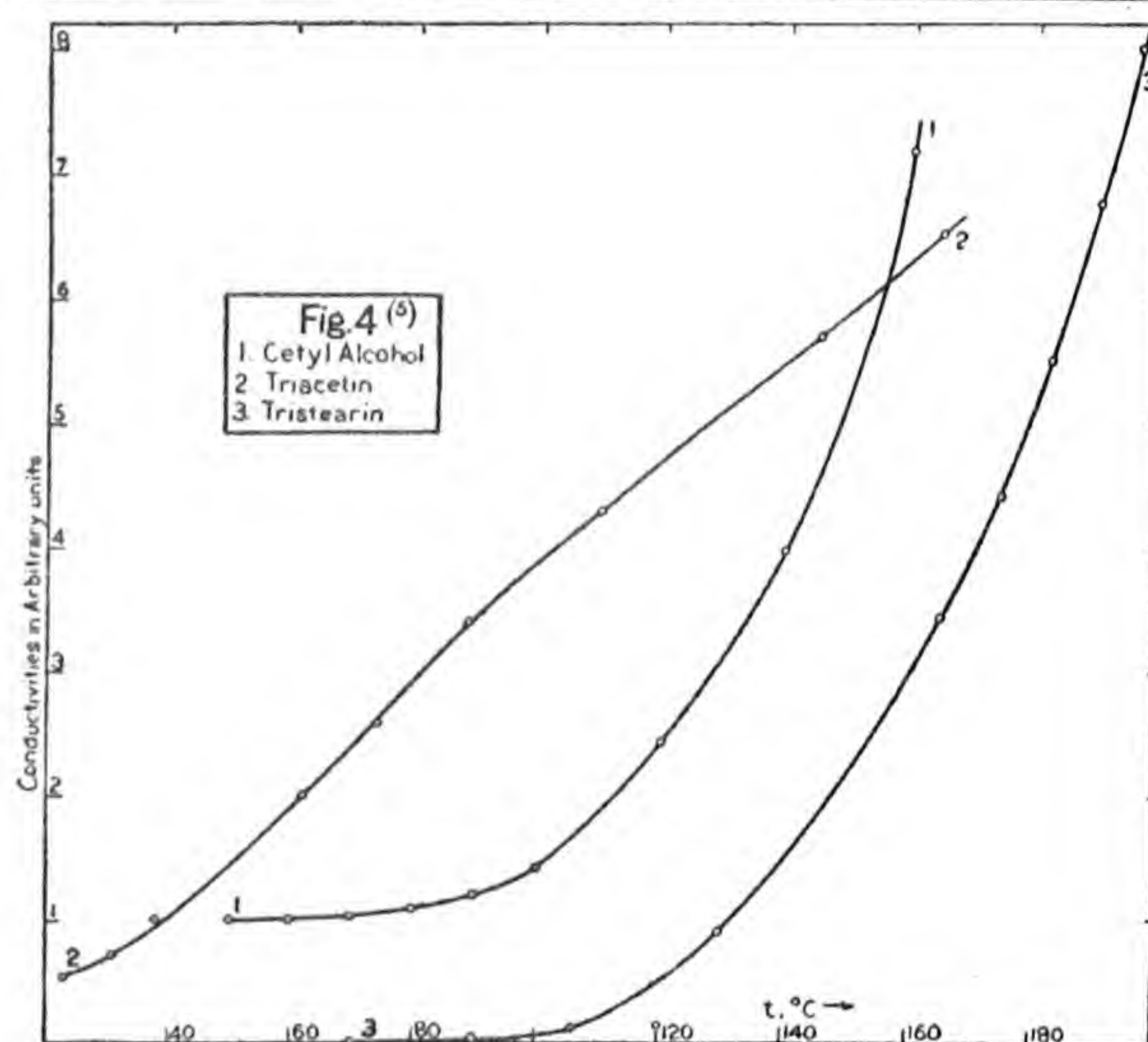
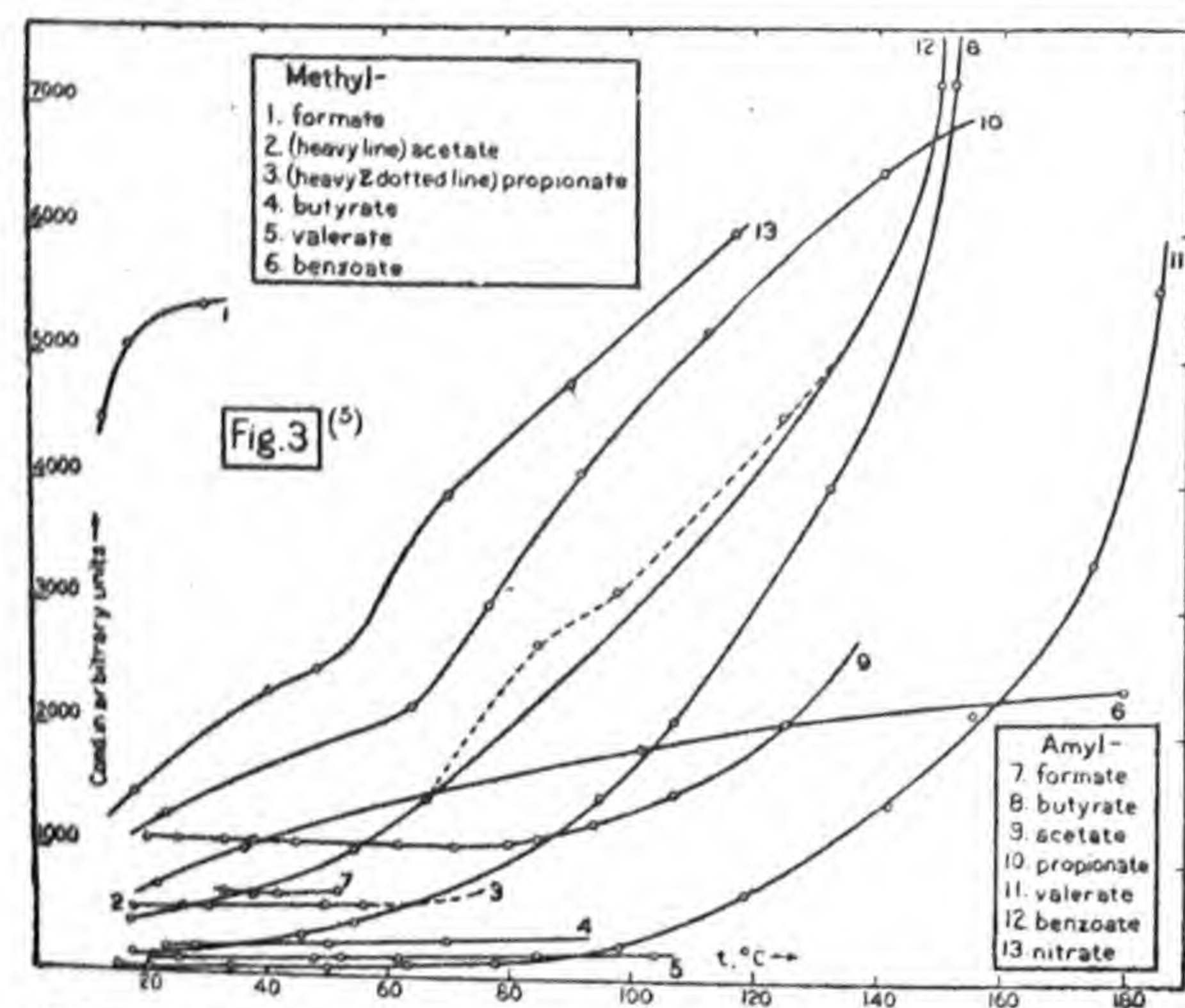
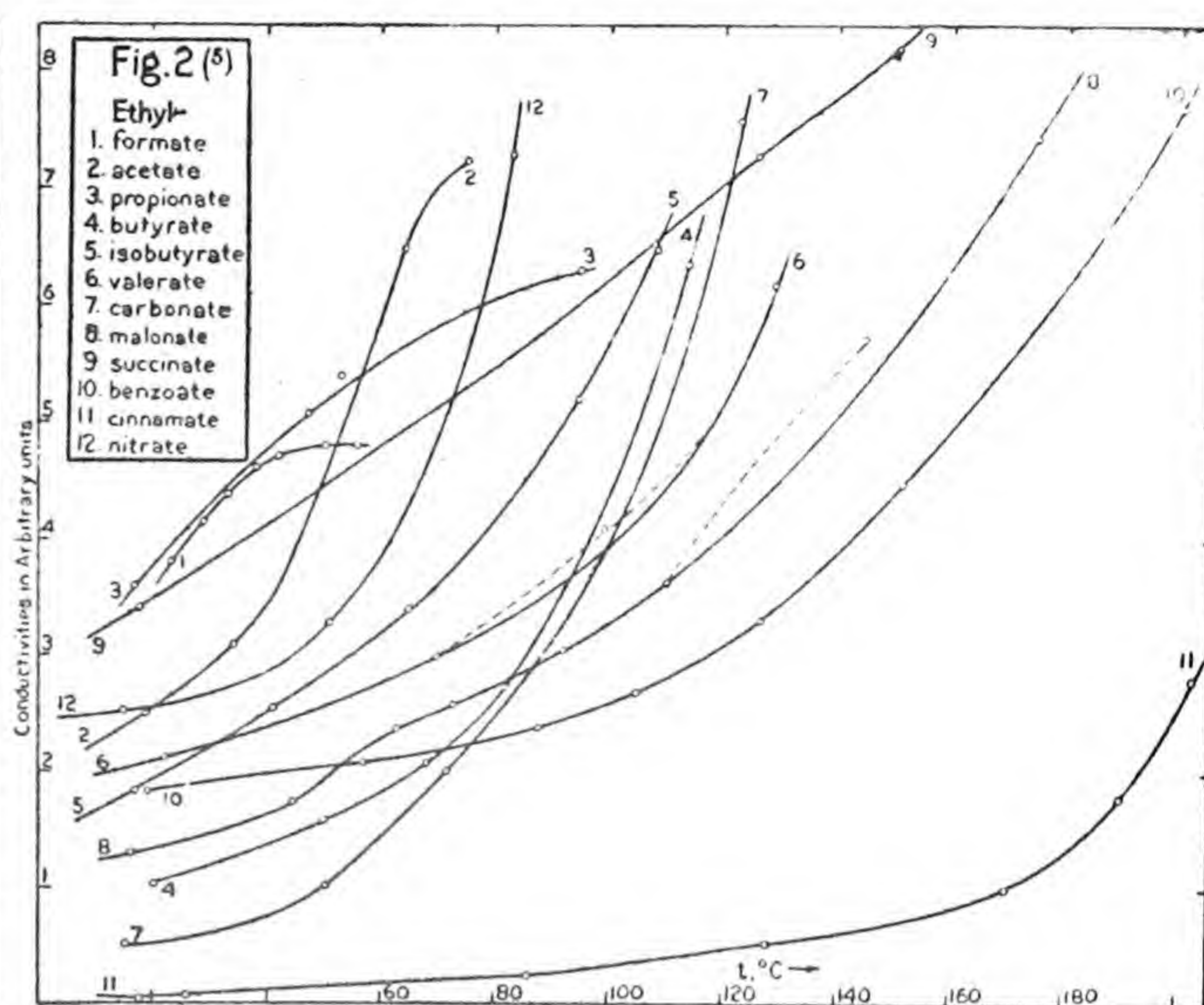
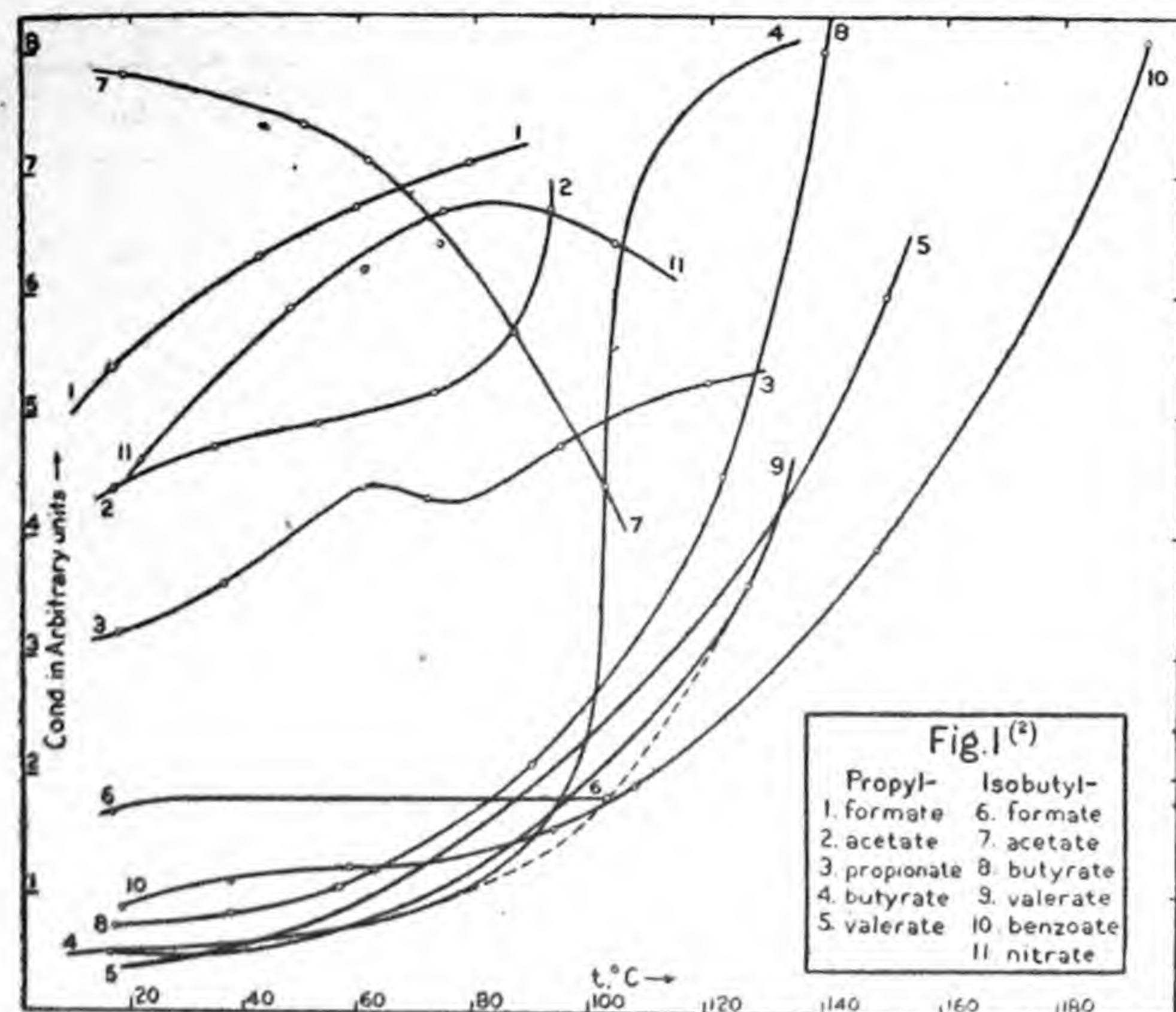
Formula	Name	t, °C	$\kappa = A \times 10^{-n}$		Lit.
			A	n	
C <sub>7</sub> H <sub>5</sub> NS.....	Phenyl isothiocyanate	25	14	7	(84)
C <sub>7</sub> H <sub>6</sub> O.....	Benzaldehyde	18	17	8	(26)
		20	4	7	(42, 108)
		25	15	8	(26, 128)
C <sub>7</sub> H <sub>6</sub> O <sub>2</sub> .....	Benzoic acid	125	3	9	(97.2)
C <sub>7</sub> H <sub>6</sub> O <sub>2</sub> .....	Salicylaldehyde	0	1	7	(123)
		25	16	8	(80)
C <sub>7</sub> H <sub>7</sub> NO <sub>2</sub> .....	o-Nitrotoluene	25	< 2	7	(80)
C <sub>7</sub> H <sub>7</sub> NO <sub>2</sub> .....	m-Nitrotoluene	25	< 2	7	(80)
C <sub>7</sub> H <sub>8</sub> .....	Toluene		< 1	14	(23); cf. (76, 110, 111)
C <sub>7</sub> H <sub>8</sub> O.....	Benzyl alcohol	25	18	7	(80)
C <sub>7</sub> H <sub>8</sub> O.....	m-Cresol	25	< 17	9	(101)
C <sub>7</sub> H <sub>8</sub> O <sub>2</sub> .....	Guaiacol	25	28	8	(101)
C <sub>7</sub> H <sub>9</sub> N.....	Benzylamine	25	< 17	9	(101)
C <sub>7</sub> H <sub>9</sub> N.....	o-Toluidine	25	< 2	6	(101)
C <sub>7</sub> H <sub>9</sub> N.....	p-Toluidine	100	62	9	(6)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub> .....	Diethyl malonate	"Non."; see Fig. 2			
C <sub>7</sub> H <sub>14</sub> O <sub>2</sub> .....	Amyl acetate; see Fig. 3				
C <sub>7</sub> H <sub>14</sub> O <sub>2</sub> .....	Ethyl valerate; see Fig. 2				
C <sub>7</sub> H <sub>14</sub> O <sub>2</sub> .....	Propyl butyrate; see Fig. 1				
C <sub>7</sub> H <sub>16</sub> .....	Heptane		< 1	13	(24, 56)
C <sub>8</sub> H <sub>7</sub> N.....	Benzyl cyanide	0	1	7	(127); cf. (108)
		25	< 5	8	(131)
C <sub>8</sub> H <sub>7</sub> N.....	Tolunitrile	25	57	7	(101)
C <sub>8</sub> H <sub>8</sub> O.....	Acetophenone	16.5	21	8	(25); cf. (89, 80)
		25	6	9	(88)
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub> .....	p-Methoxybenzaldehyde (anisaldehyde)	0	8	8	(128)
		20	86	9	(108)
		25	12	8	(130)
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub> .....	Methyl benzoate; see Fig. 3				
C <sub>8</sub> H <sub>10</sub> .....	Xylene		< 1	15	(16); cf. (24, 76)
C <sub>8</sub> H <sub>10</sub> O.....	o-Cresyl methyl ether	25	< 17	9	(101)
C <sub>8</sub> H <sub>10</sub> O.....	Phenetole	25	< 17	9	(101)
C <sub>8</sub> H <sub>14</sub> O <sub>2</sub> .....	Isobutyric anhydride	0	1	7	(125)
		25	16	8	
C <sub>8</sub> H <sub>14</sub> O <sub>4</sub> .....	Diethyl succinate; see Fig. 2				
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub> .....	Caprylic acid	80	< 4	13	(97.2)
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub> .....	Amyl propionate; see Fig. 3				
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub> .....	Isobutyl butyrate; see Fig. 1				
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub> .....	Propyl valerate; see Fig. 1				
C <sub>8</sub> H <sub>7</sub> N.....	Quinoline	0	16	9	(84); cf. (101)
		25	22	9	
		50	74	9	
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub> .....	Ethyl benzoate	19	< 2	10	(42)
		25	< 1	9	(69, 76, 71)
C <sub>9</sub> H <sub>14</sub> O <sub>4</sub> .....	Triacetin; see Fig. 4				
C <sub>9</sub> H <sub>16</sub> O <sub>2</sub> .....	Amyl butyrate; see Fig. 3				
C <sub>9</sub> H <sub>16</sub> O <sub>2</sub> .....	Isobutyl valerate; see Fig. 1				
C <sub>9</sub> H <sub>20</sub> .....	Nonane	25	< 17	9	(101)
C <sub>10</sub> H <sub>7</sub> Br.....	Bromonaphthalene	25	4	11	(97.2)
C <sub>10</sub> H <sub>8</sub> .....	Naphthalene	82	4	10	(97.2); cf. (75)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub> .....	Eugenol	25	< 17	9	(101)
C <sub>10</sub> H <sub>14</sub> .....	Cymene	25	< 2	8	(93)
C <sub>10</sub> H <sub>16</sub> .....	d(l)-Limonene	18	3	12	(24)
		25	< 17	9	(101)
C <sub>10</sub> H <sub>16</sub> .....	Pinene	23	< 2	10	(42)
C <sub>10</sub> H <sub>16</sub> .....	Terpinene	25	< 17	9	(101)
C <sub>10</sub> H <sub>16</sub> O.....	Menthone	2	< 17	9	(101)
C <sub>10</sub> H <sub>16</sub> O.....	α-Terpineol	25	< 17	9	(101)
C <sub>10</sub> H <sub>18</sub> O <sub>2</sub> .....	Acetylmethyl hexyl ketone	25	< 17	9	(101)
C <sub>10</sub> H <sub>20</sub> O <sub>2</sub> .....	Amyl valerate; see Fig. 3				
C <sub>11</sub> H <sub>15</sub> O <sub>2</sub> .....	Ethyl cinnamate; see Fig. 2				
C <sub>11</sub> H <sub>15</sub> O <sub>2</sub> .....	Ethyl benzoylacetate	0	7	8	(127)
		25	8	8	(128)
C <sub>11</sub> H <sub>14</sub> O <sub>2</sub> .....	Isobutyl benzoate; see Fig. 1				
C <sub>12</sub> H <sub>11</sub> I <sub>3</sub> N.....	Quinolinium n-propyl triiodide; see Fig. 5				
C <sub>12</sub> H <sub>15</sub> O <sub>2</sub> .....	Amyl benzoate	25	< 17	9	(101)
C <sub>12</sub> H <sub>15</sub> I <sub>3</sub> N.....	Quinolinium butyl and isobutyl triiodide; see Fig. 5				
C <sub>14</sub> H <sub>5</sub> O <sub>4</sub> .....	Alizarin	233	99**	-4	(75)
C <sub>14</sub> H <sub>10</sub> .....	Anthracene	230	3	10	(97.2); see Fig. 8
C <sub>14</sub> H <sub>15</sub> O <sub>2</sub> .....	Benzyl benzoate	25	< 1	9	(76, 71)

|| Other temperatures also.

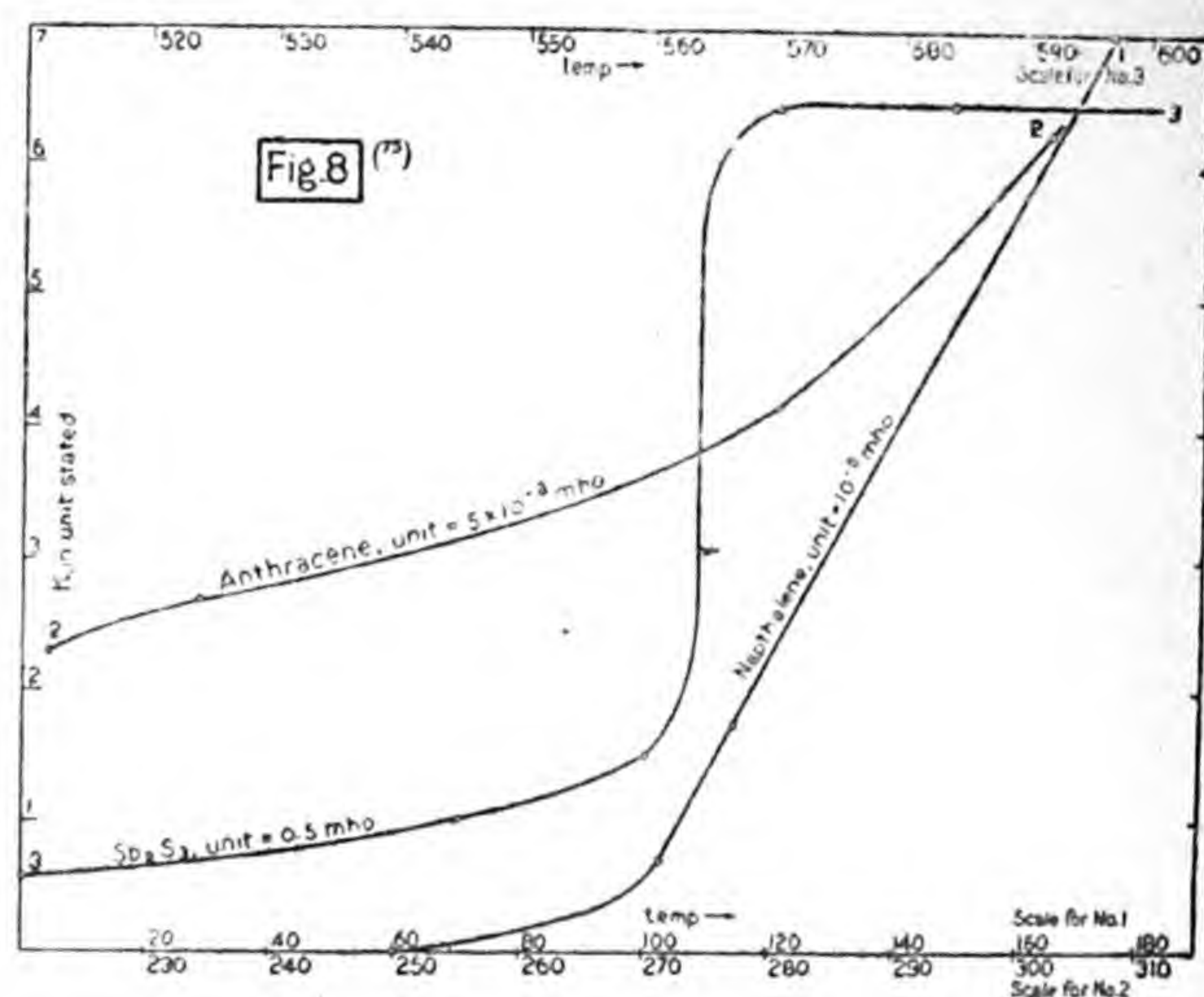
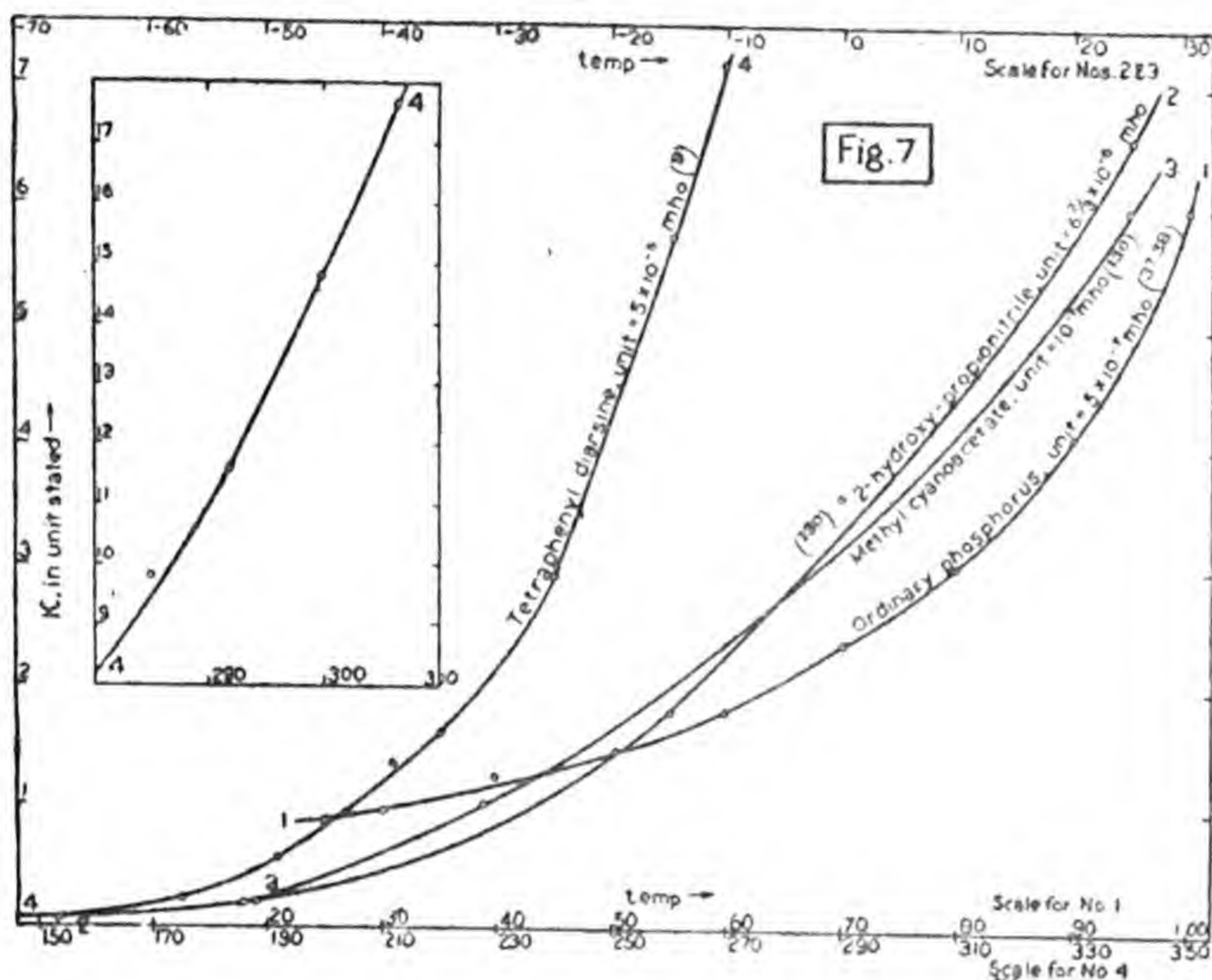
¶ Probably high.

\*\* With a polarisation of 1.5 volt.









C-Table.—(Continued)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$		Lit.
			A	n	
C <sub>12</sub> H <sub>15</sub> N.....	Dibenzylamine	25	17	9	(191)
C <sub>16</sub> H <sub>32</sub> O <sub>2</sub> .....	Palmitic acid	80	< 4	13	(97.2)
C <sub>18</sub> H <sub>34</sub> O.....	Cetyl alcohol; see Fig. 4				
C <sub>18</sub> H <sub>34</sub> O <sub>2</sub> .....	Oleic acid	15	< 2	10	(42)
C <sub>18</sub> H <sub>36</sub> O <sub>2</sub> .....	Stearic acid.....	80	< 4	13	(97.2)
C <sub>24</sub> H <sub>20</sub> As <sub>2</sub> .....	Tetraphenyldiarsine..	151.5	47	8	(6); see Fig. 7
C <sub>57</sub> H <sub>110</sub> O <sub>6</sub> .....	Tristearin; see Fig. 4				

Substance	t, °C	$\kappa = A \times 10^{-n}$		Lit.
		A	n	
Almond oil.....				(76)
Benzine.....		< 1	12	(10, 27, 83, 111)
Castor oil.....				(76)
Kerosene.....	25	< 17	9	(101)
Ligroin.....		59	17	(118)
Linseed oil.....		1	16	(76)
Olive oil.....		1	13	(118); cf. (76)
Paraffin oil.....		7	17	(118); cf. (53)
Petroleum.....		3	13	(118)
Petroleum ether...		34	16	(118); cf. (27)
		1	18	(55); cf. (27)
Turpentine.....		2	13	(83)
Vaseline (oil of)...		8	17	(118); cf. (27, 76, 83)

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Archibald, 1, 29: 665; 07. (2) Archibald, 1, 29: 1416; 07. (3) Arndt and Ploetz, 7, 121: 439; 26. (4) Bagster and Steele, 83, 8: 51; 12. (5) Bartoli, 36, 24 II: 156; 94. (6) Baskov, 53, 45: 1604; 13. (6.5) Belladen, 36, 57: 407; 27. (7) Bergius, 7, 72: 338; 10. (8) van der Bijl, 8, 39: 170; 12. (9) Borgstrom and Dewar, 1, 44: 2915; 22.
- (10) Bouty, 6, 27: 62; 92. (11) Bregmann, Diss., Lausanne, 10, 4: 931; 22. (12) Bruner, 25, 36: 3297; 03. (13) Bruner and Bekier, 7, 84: 570; 13. (14) Bruner and Galecki, 7, 84: 513; 13. (14.5) Bruns, 7, 118: 89; 25. (15) Cady and Lichtenwalter, 1, 35: 1434; 13. (16) Campbell, 3, 23: 668; 12. (17) Carrara and Levi, 36, 32 II: 36; 02. (18) Carvallo, 16, 1: 171; 14. (19) Carvallo, 16, 2: 142; 14.
- (20) Cattaneo, 22, 2 II: 112; 93. (21) Cattaneo, 22, 4 II: 63; 95. (22) Centnerswer, 7, 39: 217; 02. (23) di Ciommo, 96, 4: 291; 02. (24) di Ciommo, 59, 3: 97; 02. (25) Creighton, 7, 81: 543; 13. (26) Creighton and Way, 143, 186: 675; 18. (27) Curie, 34, 124: 420; 02. (28) Danner and Hildebrand, 1, 44: 2824; 22. (29) Davis and Jones, 7, 81: 68; 12.
- (30) Dennis and Hance, 136, 124: 66; 22. (31) Dutoit, 9, 12: 642; 06. (32) Dutoit and Duperthuis, 42, 6: 699; 08. (33) Dutoit and Friderich, 27, 19: 321; 98. (34) Dutoit and Gyr, 42, 7: 189; 09. (35) Elsey, 1, 42: 2454; 20. (36) Exner, 3, 15: 412; 82. 75, 84 II: 511; 82. (37) Fousereau, 51, 4: 189; 85. (38) Fousereau, 6, 5: 317; 85. (38.5) Franklin and Gibbs, 1, 29: 1389; 07. (39) Franklin and Kraus, 11, 23: 277; 00.

- (40) Franklin and Kraus, 1, 27: 191; 05. (41) Frenzel, 9, 6: 477; 00. (42) Gates, 50, 15: 97; 11. (42.5) Germann, 166, 61: 70; 25. (43) Glockler, 197, 12: 522; 26. (44) Godlewski, 42, 3: 393; 05. (45) Gomberg, 11, 25: 317; 01. (46) Grunmach, 8, 28: 217; 09. (47) Guy and Jones, 11, 46: 131; 11. (48) Hantzsch, 7, 61: 257; 08. (49) Hantzsch and Caldwell, 7, 58: 575; 07.
- (50) Hantzsch and Caldwell, 7, 61: 227; 08. (51) Hantzsch and Meyer, 25, 43: 336; 10. (51.5) Hartley and Raikes, 4, 127: 524; 25. (52) Hevey, 9, 16: 672; 10. (53) Hodgson, 3, 18: 252; 09. (54) Hopfgartner, 57, 34: 1313; 13. (55) Jaffé, 8, 26: 257; 08. (56) Jaffé, 8, 28: 326; 09. (57) Jaffé, 8, 32: 148; 10. (58) Johnstone, 292, 13: 191; 14. (59) Jones and Lindsay, 11, 28: 329; 02.
- (60) Jones and McMaster, 11, 36: 325; 06. (61) Jones and Mahin, 7, 69: 389; 09. (62) Jones and Rouiller, 11, 36: 427; 06. (63) Jones and Veazey, 7, 61: 641; 08. (64) Julien, 1, 47: 1799; 25. (65) Kahlenberg, 7, 46: 64; 03. (66) Kahlenberg and Lincoln, 50, 3: 12; 99. (67) Kahlenberg and Ruboff, 50, 7: 254; 03. (68) Kahlenberg and Schlundt, 50, 6: 447; 02. (69) Kendall and Brakeley, 1, 43: 1826; 21.
- (70) Kendall and Gross, 1, 43: 1426; 21. (71) Kendall and Wright, 1, 42: 1776; 20. (72) Keyes and Winningshoff, 1, 38: 1178; 16. (73) Klemensiewicz, 163, 1908: 485. (74) Koch, 8, 50: 482; 93. (75) Koenigsberger and Schilling, 8, 32: 179; 10. (76) Koller, 75, 98 IIa: 201; 90. (77) Lenher, 1, 43: 29; 21. (78) Lenher, 1, 44: 1668; 22. (79) Ley, 25, 38: 973; 05.
- (80) Lincoln, 50, 3: 457; 99. (81) Linde, 8, 56: 546; 95. (82) McIntosh, 50, 11: 306; 07. (83) Malclès, 6, 16: 153; 09. (84) Mathews, 50, 9: 641; 05. (85) Mittasch, 7, 46: 37; 03. (86) Moles and Gómez, 7, 90: 594; 15. (87) Monckman, 5, 46: 136; 90. (88) Morgan and Lammert, Columbia Univ., 0, 1, 46: 881; 24. (89) Moureu, Boutaric and Dufraisse, 42, 18: 333; 20.
- (90) Mulliken, 11, 15: 523; 93. (91) Novák, 3, 44: 9; 97. (92) Partington, 4, 99: 1937; 11. (93) Patten, 50, 6: 554; 02. (94) Pearce, 50, 19: 14; 15. (95) Philip and Courtman, 50, 97: 1261; 10. (96) Polliack, Diss., Lausanne, 1913. (96.5) Quam and Wilkinson, 1, 47: 989; 25. (97) Rabinovich, 93, 129: 60; 23. (97.1) Rabinovich, 7, 119: 59; 26. (97.2) Rabinovich, 7, 119: 70; 26. (97.5) Rabinovich, 7, 119: 79; 26. (98) Rimbach and Weitzel, 7, 79: 279; 12. (99) Sakhanov and Prsheborovskii, 9, 20: 39; 14.
- (100) Sakhanov and Rabinovich, 53, 47: 849; 15. (101) Sammis, 50, 10: 593; 06. (102) Schall, 7, 14: 701; 94. (103) Schall, 9, 14: 397; 08. (104) Schlamp, 7, 14: 272; 94. (105) Schlesinger and Calvert, 1, 33: 1924; 11. (106) Schlesinger and Coleman, 1, 38: 271; 16. (107) Schlesinger and Martin, 1, 36: 1589; 14. (108) Schmidt, 7, 75: 305; 11. (109) Schmidt and Jones, 11, 42: 37; 09.
- (110) Schweidler, 8, 4: 307; 01. (111) Schweidler, 8, 5: 483; 01. (112) Shaw, 50, 17: 162; 13. (113) Shinn, 50, 11: 537; 07. (114) Steele, McIntosh and Archibald, 62, 205: 99; 06. 7, 55: 129; 06. (115) Stenquist, 9, 12: 860; 06. (116) Svedberg, 20, 9: No. 9; 13. (117) Tijmstra, 2, 49: 345; 04. (118) Trapesnikow, 242, 57: 227; 12. (119) Turner, 11, 40: 558; 08.
- (120) Vignon, 34, 148: 844; 09. (121) Völlmer, 8, 52: 328; 94. (122) Walden, 93, 25: 209; 00. (123) Walden, 93, 29: 371; 02. (124) Walden, 7, 43: 385; 03. (125) Walden, 7, 46: 103; 03. (126) Walden, 25, 38: 345; 05. (127) Walden, 7, 54: 129; 06. (128) Walden, 7, 55: 683; 06. (129) Walden, 83, 6: 71; 10.
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ELECTRICAL CONDUCTIVITY OF ELECTROLYTIC CONDUCTORS  
AT HIGH TEMPERATURES

E. B. MILLARD

The published values of the conductivities of compressed powders (*p*) are, in general, quite discordant; they are here included by literature reference only. The numerical data refer either to molten materials (*l*) or to solidified melts (*s*); in general, the latter form part of a continuous series including the former, but in some cases solid rods (*r*), either cast or machined from a solidified melt, were used. Some data refer to the undercooled melt; when so stated by the author, they are listed, like other molten materials, under *l*; in all other cases, data for temperatures below the melting point are taken as referring to a solid and are placed under (*s*). For compressed powders of metallic nitrides, see (68); for Auer mantle at 1200°C, see (66); for recent discussions, see (16, 20, 38, 60, 61, 62). Specific conductivity =  $\kappa = C \times 10^n \text{ ohm}^{-1} \text{ cm}^{-1}$ ; if  $n = 0$ ,  $\kappa = C$ ;  $t$  = temperature, °C;  $\alpha(10)^{-3} = (R_t - R_0)/R_0 t$ , where  $R_0$ ,  $R_t$  = resistance of same solid specimen at 0°C, at  $t$ , °C.

Im allgemeinen sind die veröffentlichten Werte über die Leitfähigkeit komprimierter Pulver (*p*) ganz widersprechend und werden nur durch die Literaturstellen angegeben. Die numerischen Daten beziehen sich entweder auf geschmolzenes Material (*l*) oder feste Schmelzen (*s*). Im allgemeinen sind letztere Bestandteile einer ununterbrochenen Serie die ersteren einschliessend, aber in manchen Fällen werden feste Stäbe (*r*) verwendet, die entweder gegossen oder aus einer festen Schmelze maschinell hergestellt wurden. Manche Daten beziehen sich auf unterkühlte Schmelzen. Ist dies vom Autor angegeben, so stehen die Daten wie auch die anderen Schmelzen unter *l*. In allen anderen Fällen, bei einer Temperatur unterhalb des Schmelzpunktes werden die Daten als auf den festen Zustand sich beziehend angenommen und stehen dann unter (*s*). Für gepresste Pulver von Metallnitriden, siehe (68); für Auerstrümpfe bei 1200°C, siehe (66); neuere Diskussionen darüber, siehe (16, 20, 38, 60, 61, 62). Spezifische Leitfähigkeit =  $\kappa = C \times 10^n \text{ Ohm}^{-1} \text{ cm}^{-1}$ ; wenn  $n = 0$ ,  $\kappa = C$ ;  $t$  = Temperatur, °C;  $\alpha(10)^{-3} = (R_t - R_0)/R_0 t$ , wo  $R_0$ ,  $R_t$  = Widerstand einiger fester Formen bei 0°C bzw.  $t$ , °C bedeutet.

En général, les valeurs publiées concernant les conductibilités des poudres comprimées (*p*) sont tout à fait discordantes, aussi ne sont-elles mentionnées ici que par leur références bibliographiques. Les données numériques se rapportent soit à des matières fondues (*l*) soit à des matières fondues solidifiées (*s*); en général ces dernières constituent une partie d'une série continue comprenant les premières, mais dans certains cas il a été fait usage de baguettes solides (*r*) préparées soit par moulage soit par usinage à partir d'une masse fondue solidifiée. Certaines données se rapportent à des liquides surfondus; lorsque cet état a été établi par l'auteur, ces données sont inscrites sous *l* comme pour les autres matières fondues; dans tous les autres cas, les données pour des températures au dessous du point de fusion se rapportent à un solide et sont placées sous (*s*). Pour les poudres comprimées des nitrures métalliques, voir (68); pour le manchon d'Auer à 1200°C, voir (66); pour les discussions récentes, voir (16, 20, 38, 60, 61, 62). Conductibilité spécifique =  $\kappa = C \times 10^n \text{ ohm}^{-1} \text{ cm}^{-1}$ ; si  $n = 0$ ,  $\kappa = C$ ;  $t$  = température, °C;  $\alpha(10)^{-3} = (R_t - R_0)/R_0 t$ , où  $R_0$ ,  $R_t$  = résistance de la même éprouvette solide à 0°C, à  $t$ , °C.

In generale i valori pubblicati delle conducibilità di polveri compresse (*p*) sono molto discordanti; essi sono qui inclusi solamente come citazione bibliografica. I valori numerici si riferiscono sia a materiali allo stato di fusione (*l*) o a sostanze fuse e lasciate solidificare (*s*); in genere queste ultime sono parte di una serie continua che include anche le precedenti, ma in alcuni casi furono usate bacchette (*r*) o preparate di getto o ricavate al tornio. Alcuni valori si riferiscono a sostanze mantenute liquide allo stato di sopraffusione; quando l'affermazione è fatta dall'autore i valori sono inclusi nell'elenco dei materiali allo stato di fusione (*l*); in tutti gli altri casi invece i valori per temperature inferiori al punto di fusione sono supposti riferentisi allo stato solido e sono collocati sotto (*s*). Per le polveri compresse di azoturi metallici, vedi (68); per le reticelle Auer a 1200°C, vedi (66); per discussioni recenti, vedi (16, 20, 38, 60, 61, 62). Conducibilità specifica =  $\kappa = C \times 10^n \text{ ohm}^{-1} \text{ cm}^{-1}$ ; se  $n = 0$ ,  $\kappa = C$ ;  $t$  = temperatura, °C;  $\alpha(10)^{-3} = (R_t - R_0)/R_0 t$ , dove  $R_0$ ,  $R_t$  = resistenza dello stesso campione solido a 0°C e a  $t$ , °C.

## I. Pure Substances

## A-B-TABLE; STANDARD ARRANGEMENT

v. Vol. III, p. viii

Unit of  $\kappa = 1 \text{ ohm}^{-1} \text{ cm}^{-1}$ ; temperature =  $t$ , °C;  $\kappa = C \times 10^n$ 

TeCl <sub>2</sub> (64)		TeCl <sub>4</sub> (64)		NH <sub>4</sub> NO <sub>3</sub> —(Cont'd)	
<i>t</i>	<i>C</i>	<i>t</i>	<i>C</i>	<i>t</i>	<i>C</i>
<i>l</i> , <i>n</i> = -3		<i>l</i> , <i>n</i> = -3		<i>l</i> , <i>n</i> = -3	
206	42.0	236	114.5	202	0.397
210	45.8	254	136	213	0.447
221	58.9	277	161	SbCl <sub>3</sub> (13); cf. (37)	
230	66.8	290	175	<i>l</i> , <i>n</i> = -3	
235	71.2	316	203	73	0.11
250	89.3	NH <sub>4</sub> NO <sub>3</sub> (23)		SbBr <sub>3</sub> (31)	
252	90.4	<i>l</i> , <i>n</i> = 0		<i>l</i> , <i>n</i> = -6	
271	113	162	2.794	99	244
271	114	185	2.183	109	261
290	133	(49)		127	317
304	150	172	0.320	158	364
305	151	187	0.369	178	405
				197	446

SbI <sub>3</sub> (31)		BiCl <sub>3</sub> —(Cont'd)		C <sub>2</sub> H <sub>5</sub> NH <sub>2</sub> .HNO <sub>3</sub> *	
<i>t</i>	<i>C</i>	<i>t</i>	<i>C</i>	<i>t</i>	<i>C</i>
<i>l</i> , <i>n</i> = -6		<i>l</i> , <i>n</i> = -6		<i>l</i> , <i>n</i> = -6	
169	306	315	506	25	23.0
172	334	335	533	43	39.8
180	347	350	555	53	50.2
184	360	C, <i>p</i> (53)		70	67.7
190	372	(CH <sub>3</sub> ) <sub>2</sub> NH.HNO <sub>3</sub> *		78	75.2
204	382	74	178	90	87.9
218	431	78	187	101	98.7
225	440	89	210	(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> NH.HNO <sub>3</sub> *	
230	442	98	234	100	75.9
239	461	112	259	105	80.5
254	482	C <sub>2</sub> H <sub>5</sub> NH <sub>2</sub> .HCl*		116	89.1
266	491	100	50.5	125	96.5
307	586	110	60.1	C <sub>6</sub> H <sub>5</sub> N(CH <sub>3</sub> ) <sub>2</sub> .HBr†	
378	683	122	71.6	70	8.97
BiCl <sub>3</sub> (64)		130	79.3	88	33.2
<i>l</i> , <i>n</i> = -3		* <i>l</i> , <i>n</i> = -3 (65).		100	49.9
266	442	† <i>l</i> , <i>n</i> = -4 (65).		110	64.3
295	481			119	764



<b>ZrSiO<sub>4</sub>, <i>p</i> (44)</b> <b>SnS (30)</b> $r, \alpha = -6.62$ $15^\circ < t < 920^\circ$ $\rho_0 = 1071 \text{ ohm cm}$		<b>TlBr.—(Cont'd)</b> $t \quad   \quad C$ $l, n = 0$ 460   0.807 500   0.905 550   1.024 600   1.127		<b>CdCl<sub>2</sub>—(Cont'd)</b> $t \quad   \quad C$ 750   2.32 755   2.30 795   2.37 801   2.37		<b>Cu(NO<sub>3</sub>)<sub>2</sub>·6H<sub>2</sub>O, <i>s</i> (34)</b> <b>AgCl (42, 58)</b> $t \quad   \quad C$ $s, n = -3$ 250   0.30 300   1.5 350   6.5 400   26 450   112 $l, n = 0$ 500   4.25* 550   4.35 600   4.45 650   4.55 700   4.65 750   4.8 800   4.9 <i>p, s</i> (10, 24, 40) * $\pm 0.05$ .		<b>AgI.—(Cont'd)</b> $t \quad   \quad C$ $l, n = 0$ 550   2.3† 600   2.35 650   2.4 700   2.45 750   2.5 800   2.6 $s$ (24) * Transition temp. † $\pm 0.1$ .		<b>WCl<sub>6</sub> (64); cf. (13)</b> $t \quad   \quad C$ $l, n = -6$ 280   1.98 285   2.13 290   2.28 295   2.44 300   2.60 305   2.85 310   3.11 315   3.38 320   4.05 325   5.13 330   6.94	
<b>PbO<sub>2</sub>, <i>p</i> (55); cf. (21)</b> <b>PbCl<sub>2</sub> (43, 49)</b> $t \quad   \quad C$ $l, n = 0$ 500   1.33 525   1.57 550   1.70 575   1.84 600   1.95 650   2.25 700   2.5 $p$ (36)		<b>TlI (58)</b> $s, n = -3$ 250   0.10 300   0.39 350   1.02 400   2.73 429   4.80 $l, n = 0$ 439   0.528 450   0.551 500   0.651 550   0.747 600   0.840 $s$ (24)		<b>HgCl<sub>2</sub> (31)</b> $l, n = -3$ 276   0.77 $s$ (31)		<b>HgBr<sub>2</sub> (31)</b> $l, n = -3$ 132   1.46 $s$ (31)		<b>Ag<sub>2</sub>S, <i>p</i> (45, 59)</b> <b>AgNO<sub>3</sub> (27, 49)</b> $l, n = 0$ 200   0.65 225   0.75 250   0.85 275   0.95 300   1.06 325   1.16 350   1.27 $s$ (48)		<b>UCl<sub>4</sub> (64)</b> $l, n = 0$ 570   0.34 598   0.42 620   0.48	
<b>PbBr<sub>2</sub> (43)</b> $l, n = -3$ 372   540 382   612 392   648 402   684 412   720 422   756 432   790 442   824 452   857 462   890 472   922 482   953 492   984 $p$ (36)		<b>Tl<sub>2</sub>S, <i>l, s</i> (46)</b> <b>ZnCl<sub>2</sub> (15)</b> $s, n = -3$ 319   0.2 324   1.4 331   2.1 336   2.4 337   2.5 340   2.8 341   2.9 342   3.05 344   3.32 364   6.5 367   6.76 373   8.34 $l, n = -1$ ; cf. (23) 373   0.083 402   0.153 460   0.509 500   0.838 542   1.43 581   2.10 612   2.55 650   3.12		<b>HgI<sub>2</sub> (31)</b> $l, n = -3$ 253   11.76 260   8.48 263   7.94 288   7.14 298   6.94 320   6.62 $s$ (31)		<b>AgClO<sub>3</sub> (27)</b> $l, n = -3$ 200   321.9 210   352.7 215   367.6 220   382.9 230   413.4 240   444.4 250   474.3		<b>Mn(NO<sub>3</sub>)<sub>2</sub>·6H<sub>2</sub>O, <i>s</i> (34)</b> <b>FeS* (30, 39)</b> $r, \alpha = 7.98$ $0^\circ < t < 100^\circ$ $\rho_0 = 0.1114 \text{ ohm cm}$ * $\rho$ is greater for heating than for cooling.		<b>TaCl<sub>5</sub> (17)</b> $l, n = -6$ 235*   0.3 * 230 to 240°.	
<b>PbS (30)</b> $r, \alpha = +5.01$ $-25^\circ < t < 900^\circ$ $\rho_0 = 0.000298 \text{ ohm cm}$		<b>Tl<sub>2</sub>Se, <i>l, s</i> (46)</b> <b>Zn(NO<sub>3</sub>)<sub>2</sub>·6H<sub>2</sub>O, <i>s</i> (34)</b> <b>CdCl<sub>2</sub> (15)</b> $s, n = -2$ 534   0.07 543   0.4 554   1.2 $l, n = 0$ 576   1.925 581   1.92 591   1.92 595   1.95 597   1.97 623   2.01 635   2.06 636   2.04 660   2.14 668   2.12 692   2.17 721   2.23		<b>CuCl (15)</b> $s, n = -3$ 349   17 358   42 359   28 368   65 370   36 371   86 375   46 $n = 0$ 379   0.11 385   0.08 387   0.14 395   0.13 398   0.14 407   0.33 409   0.22 426   2.93 $l, n = 0$ 430   3.27 443   3.28 443   3.29 492   3.44 533   3.49 577   3.63 $s$ (24)		<b>AgBr (42, 58)</b> $s, n = -3$ 150   0.08 200   0.75 250   4.4 300   23 $n = 0$ 350   0.11 400   0.53 $l, n = 0$ 450   3.0* 500   3.1 550   3.2 600   3.3 650   3.3 700   3.4 750   3.5 800   3.6 <i>p, s</i> (10, 24, 40) * $\pm 0.01$ .		<b>FeS<sub>2</sub> (8)</b> $r, \rho_{20} = 1.513 \text{ ohm cm}$		<b>AlBr<sub>3</sub> (18)</b> $l, n = -6$ 195   0.09 210   0.12 225   0.15 232   0.16 243   0.18 250   0.19 260   0.20 266   0.24	
<b>ThCl<sub>4</sub> (64)</b> $l, n = 0$ 814   0.61 843   0.67 866   0.71 889   0.76 922   0.78		<b>TlCl (58)</b> $s, n = -3$ 250   0.05 300   0.24 350   0.90 400   3.70 421   6.11 $l, n = 0$ 431   1.090 450   1.170 500   1.332 550   1.532 600   1.700		<b>CuBr, <i>s</i> (24)</b> <b>CuI, <i>s</i> (24)</b> <b>Cu<sub>2</sub>S (19)</b> $l, n = 0$ 1120   76.22 1150   78.69 1200   83.30 1250   88.34 1300   94.10 1350   100.68 1400   108.25 1450   117.07 1500   127.17 1550   139.51 $p$ (45, 59)		<b>AgI (2, 42, 58)</b> $s, n = -3$ 142.4   0.333 145.0   * $n = 0$ 146.5   1.308 150   1.33 200   1.57 250   1.78 300   1.97 350   2.14 400   2.28 450   2.41 500   2.52 550   2.64		<b>FeO·TiO<sub>2</sub> (39)</b> Ilmenite <b>Co(NO<sub>3</sub>)<sub>2</sub>·6H<sub>2</sub>O, <i>s</i> (34)</b> <b>Ni(NO<sub>3</sub>)<sub>2</sub>·6H<sub>2</sub>O, <i>s</i> (34)</b> <b>MoCl<sub>5</sub> (64)</b> $l, n = -6$ 216   1.8 234   4.1 258   7.5		<b>AlI<sub>3</sub> (18)</b> $l, n = -6$ 209   2.6 218   3.3 226   3.9 238   4.7 246   5.2 260   6.3 265   6.8 270   7.4	
<b>TlBr (58)</b> $s, n = -3$ 250   0.04 300   0.12 350   0.55 400   1.6 446.5   5.15		<b>Tl<sub>2</sub>Te, <i>l, s</i> (46)</b> <b>Zn(NO<sub>3</sub>)<sub>2</sub>·6H<sub>2</sub>O, <i>s</i> (34)</b> <b>CdCl<sub>2</sub> (15)</b> $s, n = -2$ 534   0.07 543   0.4 554   1.2 $l, n = 0$ 576   1.925 581   1.92 591   1.92 595   1.95 597   1.97 623   2.01 635   2.06 636   2.04 660   2.14 668   2.12 692   2.17 721   2.23		<b>Ag<sub>2</sub>Se, <i>s</i> (24)</b> <b>Cu<sub>2</sub>Se (19)</b> $l, n = 0$ 1120   76.22 1150   78.69 1200   83.30 1250   88.34 1300   94.10 1350   100.68 1400   108.25 1450   117.07 1500   127.17 1550   139.51 $p$ (45, 59)		<b>AgI (2, 42, 58)</b> $s, n = -3$ 142.4   0.333 145.0   * $n = 0$ 146.5   1.308 150   1.33 200   1.57 250   1.78 300   1.97 350   2.14 400   2.28 450   2.41 500   2.52 550   2.64		<b>WCl<sub>5</sub> (64); cf. (13)</b> $l, n = -6$ 250   0.67 255   0.84 260   0.97 265   1.09 270   1.22 275   1.35 280   1.49 285   1.62 290   1.70 295   1.77 300   1.84		<b>ScCl<sub>3</sub> (14); cf. (64)</b> $l, n = 0$ 959   0.51 969   0.55 981   0.57 991   0.59	
		<b>Yt<sub>2</sub>O<sub>3</sub>, <i>p</i> (44)</b> <b>LaCl<sub>3</sub> (64)</b> $l, n = 0$ 950   1.30 975   1.36 1000   1.42 1025   1.49 1050   1.56 1075   1.63 1100   1.70 1135   1.77									



<b>PrCl<sub>3</sub> (64)</b>		<b>BaCl<sub>2</sub> (1)</b>		<b>NaBr.—(Cont'd)</b>		<b>NaPO<sub>3</sub>—(Cont'd)</b>		<b>Na<sub>2</sub>MoO<sub>4</sub> (33)</b>		<b>KI (2, 33, 49)</b>	
<i>t</i>	<i>C</i>	<i>t</i>	<i>C</i>	<i>t</i>	<i>C</i>	<i>t</i>	<i>C</i>	<i>t</i>	<i>C</i>	<i>t</i>	<i>C</i>
<i>l, n = 0</i>		<i>l, n = 0</i>		(2)				<i>l, n = 0</i>		<i>l, n = 0</i>	
824	0.82	900	(1.71)	800	3.06	750	0.675	843	1.411	600	1.04
849	0.89	950	1.89	850	3.23	800	0.80	905.5	1.522	650	1.15
875	0.97	1000	2.05	900	3.30	850	0.925	924.5	1.571	700	1.24
902	1.06	1050	2.19	<i>s</i> (47, 57)		900	1.05	977	1.679	750	1.35
935	1.16	1100	2.31	<b>NaI (49)</b>		950	1.175	1026	1.775	800	1.45
965	1.26	<i>s</i> (63)		<i>l, n = 0</i>		1000	1.30	1064.5	1.843	<b>K<sub>2</sub>SO<sub>4</sub> (1)</b>	
<b>NdCl<sub>3</sub> (64)</b>		<b>LiCl (15)</b>		615	2.00	<b>Na<sub>2</sub>CO<sub>3</sub> (1)</b>		1122.5	1.940	<i>l, n = 0</i>	
<i>l, n = 0</i>		<i>s, n = 0</i>		650	2.30	<i>l, n = 0</i>		1173	2.016	1100	1.84
775	0.63	577	0.15	670	2.43	850	2.92	1217	2.093	1150	1.94
807	0.71	592	0.16	680	2.59	900	3.10	1267.5	2.170	<b>KNO<sub>3</sub> (7, 23, 33, 43)</b>	
827	0.765	595	0.25	700	2.72	<i>s</i> (47)		1306	2.232	<i>l, n = -3</i>	
847	0.81	<i>l, n = 0</i>		<b>Na<sub>2</sub>SO<sub>4</sub> (1)</b>		<b>NaC<sub>2</sub>H<sub>3</sub>O<sub>2</sub> (41)</b>		1364	2.330	(250)	(360)
873	0.88	620	5.865	<i>l, n = 0</i>		Acetate		1408	2.403	(300)	(510)
900	0.945	631	5.94	900	2.23	<i>l, n = -3</i>		<b>Na<sub>2</sub>WO<sub>4</sub> (33)</b>		330	602
<b>BeCl<sub>2</sub> (64) v</b>		681	6.14	950	2.37	0	3.95	<i>l, n = 0</i>		340	634
<i>l, n = -3</i>		702	6.21	1000	2.50	5	6.2	752.5	1.091	350	664
451	3.19	746	6.40	1050	2.64	10	9.3	800	1.192	360	694
460	5.72	762	6.44	1100	2.77	15	13.2	958	1.519	370	724
472	8.68	786	6.53	<i>s</i> (63)		20	18.0	996.6	1.598	380	754
<b>MgO (26)</b>		801	6.585	<b>Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> (41)</b>		25	23.5	1066	1.718	390	784
<i>r, n = -6</i>		<b>LiNO<sub>3</sub> (27, 33)</b>		<i>l, n = -3</i>		30	30.5	1161	1.893	400	816
800	0.01	<i>l, n = 0</i>		0	6.9	35	38.5	1209	1.990	410	848
900	0.10	250	0.80	5	10.8	40	46.7	1260	2.083	420	876
1000	0.20	275	0.92	10	15.9	45	56.0	1361.5	2.250	440	937
1050	0.34	300	1.06	15	22.4	50	66.0	1412	2.335	460	996
1100	1.0	325	1.19	20	30.4	55	77.0	1501	2.453	480	1055
1150	2.6	350	1.33	25	39.3	60	89.0	<b>KOH, <i>l</i> (5)</b>		500	1116
<i>p</i> (44)		375	1.46	30	49.7	65	101.0	<b>KF (33)</b>		<b>KNH<sub>2</sub> (67)</b>	
<b>MgCl<sub>2</sub> (15)</b>		400	1.59	35	62.0	70	113.5	<i>l, n = 0</i>		<i>l, n = -3</i>	
<i>l, n = 0</i>		425	1.72	40	75.8	75	126	863.0	2.948	340	389
729	1.05	450	1.86	45	90.8	80	139	881.1	3.114	<b>K<sub>2</sub>CO<sub>3</sub> (1)</b>	
743	1.08	<i>p</i> (9)		50	106.1	85	152	901.3	3.270	<i>l, n = 0</i>	
772	1.105	<b>NaOH (4, 23); cf.</b>		55	123	90	166	905.4	3.299	900	1.95
774	1.13	(5)		60	141	<b>NaC<sub>15</sub>H<sub>31</sub>O<sub>2</sub></b>		916.3	3.418	950	2.12
822	1.23	<i>l, n = 0</i>		65	160	Palmitate (11)		968.3	3.889	1000	2.26
830	1.21	320	2.12	70	180	<i>l, n = -6</i>		975.0	3.952	<b>KC<sub>15</sub>H<sub>31</sub>O<sub>2</sub> (11)</b>	
884	1.32	350	2.38	75	201	Palmitate		<i>l, n = 0</i>		Palmitate	
909	1.39	400	2.82	80	222	<i>l, n = -6</i>		<b>KCl (1, 2, 33, 49)</b>		<i>l, n = -6</i>	
941	1.45	450	3.27	85	244	<i>l, n = -6</i>		<i>l, n = 0</i>		182	
959	1.455	<b>NaF, <i>s</i> (47)</b>		<b>NaNO<sub>3</sub> (33, 43)</b>		170	36.80	775	2.23	186	
997	1.53	<i>l, n = 0</i>		<i>l, n = 0</i>		174	44.16	800	2.34	190	
1013	1.58	<b>NaCl (49)</b>		<i>l, n = 0</i>		178	45.99	825	2.44	194	
<b>CaCl<sub>2</sub> (1, 2)</b>		<i>l, n = 0</i>		300	0.95	182	47.99	850	2.55	198	
<i>l, n = 0</i>		<i>l, n = 0</i>		325	1.05	186	53.84	875	2.65	202	
800	1.9	<i>l, n = 0</i>		350	1.15	190	58.09	900	2.76	207	
850	2.1	<i>l, n = 0</i>		375	1.25	194	60.64	925	2.86	<b>KC<sub>15</sub>H<sub>31</sub>O<sub>2</sub> (12)</b>	
900	2.3	<i>l, n = 0</i>		400	1.35	198	76.12	950	2.97	Linoleate	
950	2.5	<i>l, n = 0</i>		425	1.45	<b>NaC<sub>18</sub>H<sub>33</sub>O<sub>2</sub> (12)</b>		975	3.07	<i>l, n = -6</i>	
1000	2.7	<i>l, n = 0</i>		450	1.56	Linoleate		<i>p, s</i> (9, 10, 40, 57)		182	
1050	2.8	<i>l, n = 0</i>		475	1.66	<i>l, n = 0</i>		<b>KClO<sub>3</sub> (23)</b>		186	
<b>SrCl<sub>2</sub> (1)</b>		<i>l, n = 0</i>		500	1.76	<i>l, n = 0</i>		<i>l, n = 0</i>		190	
<i>l, n = 0</i>		<i>l, n = 0</i>		<i>p, s</i> (9, 57)		<i>l, n = -6</i>		359		194	
900	1.98	<b>NaBr (49)</b>		<b>NaNH<sub>2</sub> (67)</b>		<i>l, n = -6</i>		<i>l, n = 0</i>		198	
950	2.14	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		202	
1000	2.29	<i>l, n = 0</i>		210	0.593	<i>l, n = -6</i>		<i>l, n = 0</i>		207	
1050	2.43	<i>l, n = 0</i>		<b>NaPO<sub>3</sub> (2)</b>		<i>l, n = -6</i>		<i>l, n = 0</i>		<b>KC<sub>15</sub>H<sub>31</sub>O<sub>2</sub> (12)</b>	
1100	2.56	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		Linoleate	
<b>NaBr (49)</b>		<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		<i>l, n = -6</i>	
710	2.40	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		200	
750	2.85	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		204	
760	2.95	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		208	
780	3.27	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		212	
800	3.52	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		218	
<b>NaBr (49)</b>		<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		222	
710	2.40	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		<b>KC<sub>15</sub>H<sub>31</sub>O<sub>2</sub> (11)</b>	
750	2.85	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		Oleate	
760	2.95	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		<i>l, n = -6</i>	
780	3.27	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		200	
800	3.52	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		204	
<b>NaBr (49)</b>		<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		208	
710	2.40	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		212	
750	2.85	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		218	
760	2.95	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		222	
780	3.27	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		<b>KC<sub>15</sub>H<sub>31</sub>O<sub>2</sub> (11)</b>	
800	3.52	<i>l, n = 0</i>		<i>l, n = 0</i>		<i>l, n = -6</i>		<i>l, n = 0</i>		Oleate	



KC <sub>18</sub> H <sub>35</sub> O <sub>2</sub> (11)	
Stearate	
<i>t</i>	<i>C</i>
<i>l</i> , <i>n</i> = -6	
224	110.4
226	122.7
228	138.0
230	169.8
232	184.0
234	256.6
237	315.4
239	368.0

K <sub>2</sub> CrO <sub>4</sub> , <i>p</i> (10)	
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K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> (43)	
<i>l</i> , <i>n</i> = -3	
397	196
407	220
417	238
427	256
437	275
447	293
457	311
467	329
477	347
487	366
497	384
507	402

RbCl (15)	
<i>t</i>	<i>C</i>
<i>l</i> , <i>n</i> = 0	
733	1.49
765	1.58
769	1.59
780	1.62
819	1.70
839	1.74
873	1.81
915	1.87

RbNO <sub>3</sub> (33)	
<i>l</i> , <i>n</i> = -3	
318.8	439
341.3	490
351.3	511
357.0	524
376.0	569
379.4	573
409.0	636
422.8	666
435.9	692
448.6	720
468.7	755
493	804

CsCl (15)	
<i>t</i>	<i>C</i>
<i>l</i> , <i>n</i> = 0	
660	1.14
685	1.18
711	1.26
722	1.27
751	1.34
775	1.39
809	1.44
831	1.48

CsNO <sub>3</sub> (33)	
<i>l</i> , <i>n</i> = -3	
446.6	594
472.7	634
490.2	656
498.0	670
510.1	685
525.3	705
541.7	723
556.3	744

PbCl <sub>2</sub>		
B = PbBr <sub>2</sub>		
M % B	<i>C</i> , 200°	<i>C</i> , 250°
<i>r</i> (50), <i>n</i> = -6		
0	50	140
15	34	90
30	22	75
40	16	54
50	12	40
60	17	67
70	38	102
85	46	223
100	81	274

M % B	<i>C</i>
<i>t</i> = 300°, <i>n</i> = -3	
0	0.60
15	0.40
30	0.25
40	0.23
50	0.21
60	0.24
70	0.34
85	0.58
100	0.86

Wt % A	<i>C</i>
<i>l</i> (51), <i>n</i> = 0	
<i>t</i> = 500°C	
0.00	1.030
7.76	1.059
20.15	1.108
43.09	1.201
69.44	1.310
87.21	1.400
100.00	1.472

TiCl	
B = CdCl <sub>2</sub>	
Wt % A	<i>C</i>
<i>l</i> (51), <i>n</i> = 0	
<i>t</i> = 600°C	
0	1.971
20	1.808
35	1.781
40	1.665
50	1.566
53.7	1.522
60	1.520
75	1.564
85	1.610
90	1.664
100	1.702

<i>t</i> = 700°C	
0	2.101
20	1.990
35	1.950
40	1.857
50	1.789
53.7	1.718
60	1.720
75	1.760
85	1.818
90	1.860
100	1.951

B = AgCl	
M % A	<i>C</i>
<i>r</i> (50), <i>n</i> = -6	
<i>t</i> = 200°C	
0	50
15	65
30	86
40	104
50	92
60	75
70	65
80	32
100	13

Wt % A	<i>C</i>
<i>l</i> (51), <i>n</i> = 0	
<i>t</i> = 500°C	
0.00	3.653
22.77	2.925
42.00	2.260
63.00	1.771
79.43	1.470
100.00	1.215

TiNO <sub>3</sub> *	
B = AgNO <sub>3</sub> *	
Wt % B	<i>C</i>
<i>l</i> (51), <i>n</i> = 0	
<i>t</i> = 250°C	
0	0.436
10	0.465
25	0.512
50	0.580
75	0.695
100	0.812

\* In original, table headed TiCl and AgCl; column headed AgNO<sub>3</sub>; as it is stated that Wt. % A = 50 is equivalent to M % A = 61.02, both salts were probably nitrates.

Cd*	
B = CdCl <sub>2</sub>	
M % A	<i>C</i>
<i>l</i> (6), <i>n</i> = 0	
<i>t</i> = 580°C	
0	1.907
2.5	1.898
5.0	1.884
7.5	1.867
10	1.845
<i>t</i> = 600°C	
0	1.968
2.5	1.959
5.0	1.945
7.5	1.928
10	1.906
<i>t</i> = 620°C	
0	2.023
2.5	2.016

B = CdCl <sub>2</sub> —	
(Continued)	
M % A	<i>C</i>
5.0	2.004
7.5	1.989
10	1.969

\* Values for "commercial" products, 3.4, 7.2, and 11.5 M % A, at 10° intervals from 580 to 700°C are also given.

CdCl <sub>2</sub>	
B = KCl	
Wt % A	<i>C</i>
<i>l</i> (51), <i>n</i> = 0	
<i>t</i> = 800°C	
0	2.301
10	2.163
20	2.041
30	1.911
35	1.852
50	1.735
55	1.785
60	1.662
65	1.703
70	1.771
75	1.841
80	1.929
90	2.110
100	2.250
<i>t</i> = 900°C	
0	2.522
10	2.315
20	2.160
30	2.061
35	2.000
50	1.882
55	1.800
60	1.776
65	1.800
70	1.868
75	1.940
80	2.090
90	2.151
100	2.401

## II. Binary Mixtures

### A-B-TABLE; STANDARD ARRANGEMENT

v. Vol. III, p. viii

M = mole, M % = mole %, Wt. % = weight %, *m*<sub>A</sub> = mass of A, *l* = molten, *p* = compressed powder, *r* = solid rod, *s* = solidified melt, *κ* = specific conductivity Unit of *κ* = 1 ohm<sup>-1</sup> cm<sup>-1</sup>; *t* = temperature, °C; *κ* = *C* × 10<sup>3</sup>

I	
B = HgI <sub>2</sub> (31)	
<i>t</i>	<i>C</i>
<i>m</i> <sub>A</sub> = 10% <i>m</i> <sub>B</sub>	
<i>s</i> , <i>n</i> = -3	
110	0.046
208	0.139
226	1.18
233	3.64
<i>m</i> <sub>A</sub> = <i>m</i> <sub>B</sub>	
<i>s</i> , <i>n</i> = -3	
165	0.14
206	0.645
227	1.05

SbCl <sub>3</sub>	
B = NH <sub>4</sub> Cl, TiCl <sub>4</sub> , RbCl, or KCl	
<i>l</i> (37)	

SbBr <sub>3</sub>	
B = AlBr <sub>3</sub>	
Wt % A	<i>C</i>
<i>t</i> = 99.5°C (32)	
<i>l</i> , <i>n</i> = -6	
1.09	0.06
3.60	5.31
5.68	85.43
6.37	137.7
7.31	267.4

B = AlBr <sub>3</sub> —	
(Continued)	
Wt % A	<i>C</i>
8.75	483.5
9.85	714.8
<i>n</i> = -3	
14.15	1.647
15.27	1.924
19.33	2.884
22.31	3.601
25.58	4.267
29.91	5.348
35.10	6.331
40.00	7.303
45.59	8.248
47.98	8.607
49.52	8.982
55.28	9.894
60.19	11.646
65.29	13.212

<i>t</i>	<i>C</i>
Wt % A = 15.27	
<i>l</i> , <i>n</i> = -3	
99.5	1.924
110.3	2.173
120.3	2.363
130.5	2.492
140.3	2.542
150.0	2.515
160.6	2.411

B = AlBr <sub>3</sub> —	
(Continued)	
<i>t</i>	<i>C</i>
170.5	2.248
180.0	2.050
190.1	1.851
Wt % A = 50.35	
99.5	9.135
110.3	11.62
120.3	13.16
130.5	15.35
140.3	17.58
150.0	20.11
160.6	23.22
170.5	25.43
180.0	27.70
190.1	29.58

SnCl <sub>2</sub>	
B = PbCl <sub>2</sub>	
<i>p</i> (9)	

PbO <sub>2</sub>	
B = MnO <sub>2</sub>	
<i>s</i> (21)	



**B = AlBr<sub>3</sub>.—(Cont'd)**

$n = -6$   
Wt. % A = 7.81

$t$	$C$
99.5	120.6
110.3	127.1
120.3	135.9
130.5	133.0
140.3	128.6
150.0	121.6
160.6	107.5
170.5	96.2
180.0	84.7
190.1	71.4

$n = -3$   
Wt. % A = 14.38

$t$	$C$
99.5	2.051
110.3	2.369
120.3	2.583
130.5	2.772
140.3	2.892
150.0	2.943
160.6	2.867
170.5	2.786
180.0	2.668
190.1	2.454

Wt. % A = 21.08

$t$	$C$
99.5	5.814
110.3	7.002
120.3	8.061
130.5	9.059
140.3	10.01
150.0	10.73
160.6	11.32
170.5	11.77
180.0	11.94
190.1	11.96

**CuO**

B = MnO<sub>2</sub>,  $s$  (21)

**AgCl**

B = AgBr

M % B |  $C$   
 $s$  (50),  $n = -3$

$t$	$C$
0	0.05
10	0.08
30	0.13
40	0.16
50	0.20
60	0.23
70	0.32
80	0.38
90	0.42
100	0.46

$t = 250^\circ\text{C}$

$t$	$C$
0	0.20
10	0.35
30	0.66
40	0.92
50	1.26
60	1.56
70	2.10
80	2.31
90	2.40
100	2.60

**B = AgBr.—**

(Continued)

M % B |  $C$   
 $t = 300^\circ\text{C}$

$t$	$C$
0	1.09
10	1.68
30	3.50
40	5.52
50	7.01
60	8.17
70	10.8
80	11.9
90	12.9
100	14.0

$t = 350^\circ\text{C}$

$t$	$C$
0	5.20
10	5.49
30	16.8
40	22.0
50	32.0
60	37.0
70	42.5
80	52.0
90	58.5
100	64.2

$t = 400^\circ\text{C}$

$t$	$C$
0	24.0
10	31.8
30	57.0
40	75.3
50	120
60	140
70	164
80	235
90	272
100	304

Wt. % A |  $C$

$t$	$C$
0.00	2.924
24.65	3.130
43.00	3.246
64.00	3.409
100.00	3.653

B = KCl,  $p$  (10)

**MnO<sub>2</sub>**

B = KBr,  $s$  (21)

**AlBr<sub>3</sub>**

B = KBr

Wt. % B |  $C$   
 $t = 99.5^\circ\text{C}$  (32)

$t$	$C$
11.02	16.33
12.65	18.53
13.07	19.14
15.44	21.95
16.84	23.62
18.46	25.46

Wt. % B = 13.07

$t$	$C$
99.5	19.14
110.3	23.60
120.3	27.02
130.5	29.14

**B = KBr.—(Cont'd)**

$t$	$C$
140.3	31.85
150.0	34.74
160.6	36.75
170.5	39.33
180.0	43.02
190.1	45.47

**CaCl<sub>2</sub>**

B = NaCl

Wt. % B |  $C$   
 $l$  (51),  $n = 0$   
 $t = 850^\circ\text{C}$

$t$	$C$
0.00	2.220
2.51	2.191
5.14	2.190
10.00	2.235
20.00	2.307
35.50	2.404
40.00	2.452
42.26	2.520
50.00	2.635
60.00	2.830
75.00	3.016
80.00	3.260
100.00	3.575

$t = 950^\circ\text{C}$

$t$	$C$
0	2.580
10	2.375
40	2.576
50	2.820
75	3.230
100	3.890

B = KCl

$l$  (51),  $n = 0$

$t = 800^\circ\text{C}$

$t$	$C$
0	2.006
10	1.772
20	1.620
25	1.554
30	1.501
35	1.477
40	1.478
45	1.480
50	1.492
60	1.550
70	1.708
80	1.951
100	2.301

$t = 900^\circ\text{C}$

$t$	$C$
0	2.405
10	2.090
20	1.893
25	1.835
30	1.730
35	1.699
40	1.702
45	1.700
50	1.766
60	1.852
70	1.973
80	2.195
100	2.522

**LiCl**

B = KCl

$p$  (9)

**LiNO<sub>3</sub>**

B = NaNO<sub>3</sub>

$p$  (9)

**NaCl**

B = KCl

Wt. % A |  $C$   
 $l$  (51),  $n = 0$   
 $t = 850^\circ\text{C}$

$t$	$C$
0	2.420
5	2.441
25	2.559
50	2.862
65	3.022
75	3.159
90	3.448
100	3.575

$p$  (10)

**NaNO<sub>3</sub>**

B = KNO<sub>3</sub>

$l$  (27),  $n = 0$

$4M_A + 1M_B$

$t$	$C$
321.6	0.9119
399.1	1.224
454.1	1.401

**B = KNO<sub>3</sub>.—**

(Continued)

$t$  |  $C$   
 $1M_A + 1M_B$

$t$	$C$
320	0.7475
330	0.7890
340	0.8293
350	0.8680
360	0.9050
370	0.9410
380	0.9768
390	1.011
400	1.045
410	1.078
420	1.111
430	1.143
440	1.174
450	1.205

$1M_A + 1M_B$

$t$	$C$
320	0.6318
330	0.6668
340	0.7015
350	0.7358
360	0.7705
370	0.8055
380	0.8393
390	0.8730
400	0.9053
410	0.9370
420	0.9678
430	0.9983
440	1.028
450	1.059

**B = KNO<sub>3</sub>.—**

(Continued)

Wt. % A |  $C$   
 $l$  (51),  $n = 0$   
 $t = 350^\circ\text{C}$

$t$	$C$
0.00	0.670
17.38	0.740
45.16	0.872
71.10	1.030
100.00	1.170

$t = 400^\circ\text{C}$

$t$	$C$
0.00	0.818
17.38	0.900
45.16	1.030
71.10	1.221
100.00	1.371

See also (23)

**KCl**

B = KBr

$s$  (57)

B = K<sub>2</sub>CrO<sub>4</sub>

$p$  (10)

Permutite

Ag-, and Na-

$s$  (28)

Permutite

Ag-Na, and Ag-K

$s$  (29)

Cryolite mixtures

$l$  (3)

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THE ELECTRICAL CONDUCTIVITY AND THE IONIZATION-PRODUCT OF H<sub>2</sub>O

NIELS BJERRUM

## ELECTRICAL CONDUCTIVITY

Ice (3)	$t, ^\circ\text{C} \dots\dots\dots$	0	-4	-10	-19
	$10^{10}\kappa, (\text{mho}) \dots\dots\dots$	280	23	11	2.6

Water.—The specific conductance of pure liquid H<sub>2</sub>O (mho) at any temperature may be computed from the following equation using the appropriate value of  $p_w$  obtained from the tables which follow:

$$\log_{10} \kappa = [\log_{10} (\Delta \times d) - 3 - \frac{1}{2}p_w],$$

where  $d$  is the density of water in g/ml and  $\Delta (= \Delta_{\text{H}^+} + \Delta_{\text{OH}^-})$  is the equivalent conductance for H<sup>+</sup> + OH<sup>-</sup>, all at  $t, ^\circ\text{C}$ .

Example at 18°:  $\log_{10} \kappa = \log_{10} (315.2 + 174)(0.9986) - 3 - 7.11 = 7.42$ .  $\kappa = 0.038 \times 10^{-6}$  mho, which may be compared with the directly measured value  $0.042 \times 10^{-6}$  for Kohlrausch and Heydweiller's "best" water.

## IONIZATION PRODUCT

$K_w = [\text{H}^+][\text{OH}^-]$ ; [H<sup>+</sup>] and [OH<sup>-</sup>] are the concentrations in moles per 1000 grams of water.

VALUES OF THE IONIZATION-EXPONENT OF WATER:  $-\log_{10} K_w = p_w^*$

$t, ^\circ\text{C}$	Calculated from the conductance of the purest water†	Calculated from the hydrolysis of salts of weak acids and weak bases			
		Ionization of the salt calculated from conductance		Activity-coefficient of the ions, $f$ , calculated by means of the formula: $-\log_{10} f = 0.3\sqrt{C_i}$	
		(5, 6)	(9)	(4)	(9)
0	14.93		15.05		14.99
10	14.52	14.51		14.47	
15		14.34		14.30	
18	14.22		14.34		14.27
25	13.98	13.98	14.09	13.94	14.03
40		13.53		13.49	
50	13.25	13.29		13.25	
		(11)†	(14)†		
100		12.28			
156		11.57			
218			11.19		
306			11.46		

\*  $\text{pH}$  in pure liquid H<sub>2</sub>O =  $\frac{1}{2}p_w - \log_{10} d$ .

† The values in the table are calculated from the formula of Heydweiller (2):  $-\log_{10} K_w = 6099.6/(273 + t) + 24.25 \log_{10} (273 + t) - 66.4678$

‡ Recomputed to mole/1000 gram water

Calculated from the potential of cells with hydrogen electrodes in acid and alkaline solutions

$t, ^\circ\text{C}$	Ion-concentrations calculated by means of conductance measurements				Activity-coefficients of the ions calculated on thermodynamical basis	
	(8)	(12)	(10)	(13)	(7)*	(1)†
0	14.87				14.945	14.926
18	14.15		14.13	14.14	14.239	14.222
25	13.92	13.91	13.89		13.998	13.980
30	13.76		13.72			
37			13.50		13.626	13.590
40	13.41		13.42			
50	13.06				13.273	
60	12.90					
70	12.67					
80	12.46					
90	12.37					
100					12.29	

\* The potential measurements are made at 25°, and from the value of  $K_w$  at 25° the values at the other temperatures are calculated, using for the heat of neutralization 29 210 - 537, which gives for  $K_w$  the following formula:  $-\log_{10} K_w = 6384.7/(273.1 + t) + 26.676 \log_{10} (273.1 + t) - 73.424$

† Debye-Hückel square-root formula used as the limiting law for  $C = 0$ .

## Best values

$t, ^\circ\text{C}$	$p_w$	$t, ^\circ\text{C}$	$p_w$
0	14.93	50	13.26
5	14.72	60	13.03
10	14.53	70	12.82
15	14.34	80	12.63
18	14.23	90	12.45
20	14.16	100	12.29
25	13.99	150	11.63
30	13.83	200	11.26
35	13.67	250	11.17
37	13.61	300	11.40
40	13.52	306	11.46
45	13.39		

Computed by means of the values in the foregoing tables. Below 100° the values from potential and hydrolysis determinations based upon dissociation computed from conductance data are not used. Of the other values the greatest weight is given to the potential determinations.

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# ELECTRICAL RESISTIVITY OF (1) SINGLE CRYSTALS, (2) SOLID POOR CONDUCTORS (EXCEPT SALTS), (3) MIXTURES OF RARE EARTH OXIDES AND (4) LIQUID MIXTURES SUITABLE FOR HIGH RESISTANCES

G. M. J. MACKAY

## CONTENTS

## MATIÈRES

## INHALTSVERZEICHNIS

## INDICE

## PAGE

Pure substances.  
Minerals and other single crystals.  
Nernst and Auer mixtures containing rare earth oxides.  
Mixed liquids suitable for high resistances.  
Effect of pressure.  
Surface resistivity.  
Effect of humidity.

Substances pures.  
Minéraux et autres cristaux isolés.  
Masses de Nernst et d'Auer contenant des oxydes des terres rares.  
Mélanges liquides convenant pour hautes résistances.  
Effet de la pression.  
Résistance de surface.  
Effet de l'humidité.

Reine Stoffe.  
Mineralien und andere Einzelkristalle.  
Nernst- und Auer-Mischungen, enthaltend Oxyde seltener Erden.  
Flüssige Mischungen, die sich für hohen Widerstand eignen.  
Einfluss des Druckes.  
Oberflächen-Widerstand.  
Einfluss der Feuchtigkeit.

Sostanze pure..... 153  
Minerali ed altri cristalli singoli..... 154  
Miscele di Nernst e di Auer contenenti ossidi di terre rare..... 155  
Miscele liquide adatte per alte resistenti..... 155  
Effetto della pressione..... 155  
Resistività superficiale.  
Effetto dell'umidità..... 155

Salts (excepting conduction in single crystals), pure liquids, electrolytic solutions, and industrial materials, are specifically excluded from this section of the Tables; *v.* Index at end of Vol. VII.

In view of the large effect produced by traces of impurities, by variations in absorption, polarization, surface leakage, etc., the values given should be regarded, in most cases, as mere approximations. The resistivity of specimens of minerals from different localities may differ by several hundred fold.

For high frequency alternating current resistance, see (16, 17); for Hall effect, see (24, 27); for mixtures of oxides, see Table 3 and (42).

TABLE 1.—ELECTRICAL RESISTIVITY ( $\rho$ ) OF POOR CONDUCTORS: PURE SUBSTANCES

$\rho = A \times 10^n$ ;  $s$  = solid,  $l$  = liquid;  $\bar{5}$  denotes  $-5$ ; if  $A = 7.8$  and  $n = \bar{5}$ , then  $\rho = 7.8 \times 10^{-5}$ . (In certain cases  $\rho_t$  can be computed by means of one of the following formulae:  $\rho_t = \rho_0 \{1 + \alpha t(10)^{-3}\}$ ;  $\rho_t = \rho_0 \{1 + \alpha t(10)^{-3} \pm \beta t^2(10)^{-6}\} e^{-\alpha t/TT_0}$ ,  $T[T_0]$  = absolute temperature corresponding to  $t[0^\circ\text{C}]$ ,  $T_0 = 273.1^\circ\text{K}$ ; if  $t < 0^\circ\text{C}$  use the minus sign before the  $\beta$ . Values of coefficients are given after numerical data.) Unit of  $\rho = 1 \text{ ohm cm} = 0.3937 \text{ ohm in.}$  Centigrade temperatures,  $^\circ\text{C}$ .

## Elementary Substances

B, Cast* (47)		
$t$	$A$	$n$
0	1.8	6
600	1 ca.	0

Br (35)		
$t$	$A$	$n$
-18.5	1.25	11

C, Diamond (44)		
$t$	$A$	$n$
15	$\begin{cases} 4.7 \\ 3.2 \end{cases}$	$\begin{cases} 14 \\ 13 \end{cases}$ (2)
1030	> 1	7
1170	9.2	6
1250	4.4	6
1380	7.5	5

Ce (6)		
$t$	$A$	$n$
18	7.8	$\bar{5}$

I (34)		
$t$	$A$	$n$
4.1	1.13†	10
42.7	1.1†	8
111s	6.2	7 (5)
112l	1.4	3 (5)

La (7)		
$t$	$A$	$n$
18	5.9	$\bar{5}$

Nd (6)		
$t$	$A$	$n$
18	7.9	$\bar{5}$

P (18)		
$t$	$A$	$n$
15s	8.4	10
42s	1.6	10
25l	2.3	6

Black P† (11)		
$t$	$A$	$n$
0	1.000	0
50	6.62	$\bar{1}$
100	4.21	$\bar{1}$

Pr (6)		
$t$	$A$	$n$
18	8.8	$\bar{5}$

S (18)		
$t$	$A$	$n$
20	1.9	17 (15)
30	3.9	16 (15)
55	3.95	15
69	1.78	14
110	4.8	12
115l	9.5	11

See also p. 141

Se; see p. 141		
Si, Crystalline (267)		
$t$	$A$	$n$
$\alpha$ -form		
-189	2.90	$\bar{1}$
-30	1.13	$\bar{1}$
+15	9.0	$\bar{2}$
129	5.0	$\bar{2}$
210	3.9	$\bar{2}$

 $\alpha = 3.682$ ,  $\beta = -8.4$ ,  $q = 800$ Compounds; Standard Arrangement  
*v.* Vol. III, p. viii

Bi <sub>2</sub> O <sub>3</sub> (21)		
$t$	$A$	$n$
225	2.34	8
424	1.44	5
645	6.01	3

SiO <sub>2</sub> ; see Table 2		
TiO <sub>2</sub> (42)		
$t$	$A$	$n$
915	11.73	3
1000	7.49	3
1320	4.40	2

SnO; $\rho <$ for SnO <sub>2</sub> (42)		
SnO <sub>2</sub> (42)		
$t$	$A$	$n$
785	6.56	3
1000	2.56	2
1320	1.01	1

SnAs (32)		
$t$	$A$	$n$
-81	7.97	$\bar{5}$
+25	4.97	$\bar{5}$
250	6.36	$\bar{5}$

Sn <sub>2</sub> As <sub>3</sub> (32)		
$t$	$A$	$n$
-81	7.21	$\bar{5}$
+25	3.67	$\bar{5}$
250	6.32	$\bar{5}$

Sn <sub>3</sub> As <sub>2</sub> (32)		
$t$	$A$	$n$
-81	8.58	$\bar{5}$
+25	6.43	$\bar{5}$
250	7.91	$\bar{5}$

PbO (21)		
$t$	$A$	$n$
384	2.59	7
572	2.67	5
787	1.22	3

Si.—(Continued)		
$t$	$A$	$n$
$\beta$ -form		
210	1.62	$\bar{1}$
435	8.5	$\bar{2}$
$\gamma$ -form		
440	1.00	$\bar{1}$
835	2.2	$\bar{2}$

 $\alpha = 5.04$ ,  $\beta = -3.1$ ,  $q = 3000$ 

Te; see p. 142

PbO <sub>2</sub> § (33)		
$t$	$A$	$n$
0	9.08	$\bar{5}$

 $a = 0.6$ , if  $22^\circ \leq t \leq 84^\circ\text{C}$ 

ZnO (42)		
$t$	$A$	$n$
160	9.34	3
605	5.9	1
1000	2.60	0
1320	1.66	0

CdO (42)		
$t$	$A$	$n$
785	6.73	3
1000	7.13	2
1200	3.26	1
1330	5.0	0

CuO (21)		
$t$	$A$	$n$
12.2	2.12	6
265	3.55	$\bar{3}$ (42)
463	1.67	2
750	2.08	0 (42)
1000	3.2	$\bar{1}$ (42)
1038	9.6	$\bar{2}$
1120	1.5	$\bar{1}$ (42)

MnO; $\rho <$ for Mn <sub>2</sub> O <sub>4</sub> (42)		
Mn <sub>2</sub> O <sub>4</sub> (42)		
$t$	$A$	$n$
560	2.01	3
695	3.50	2
1000	1.43	1
1280	7.2	$\bar{1}$

Fe <sub>2</sub> O <sub>3</sub> (42)		
$t$	$A$	$n$
570	6.24	3
700	10.38	2
1000	8.23	1
1015	6.84	1



<b>Fe<sub>2</sub>O<sub>3</sub> (42)</b> <table><tr><th><i>t</i></th><th><i>A</i></th><th><i>n</i></th></tr><tr><td>125</td><td>4.74</td><td>3</td></tr><tr><td>600</td><td>1.32</td><td>1</td></tr><tr><td>1000</td><td>2.17</td><td>0</td></tr><tr><td>1320</td><td>7.7</td><td>1</td></tr></table>	<i>t</i>	<i>A</i>	<i>n</i>	125	4.74	3	600	1.32	1	1000	2.17	0	1320	7.7	1	<b>MgO (21)</b> <table><tr><th><i>t</i></th><th><i>A</i></th><th><i>n</i></th></tr><tr><td>471</td><td>2.71</td><td>8</td></tr><tr><td>933</td><td>2.4</td><td>5</td></tr><tr><td>1280</td><td>1.0</td><td>5</td></tr><tr><td>1341</td><td>2.25</td><td>6</td></tr></table>	<i>t</i>	<i>A</i>	<i>n</i>	471	2.71	8	933	2.4	5	1280	1.0	5	1341	2.25	6	<b>Cu<sub>3</sub>As, Whitneyite (Orth)</b> <table><tr><th><i>t</i></th><th><i>A</i></th><th><i>n</i></th><th>Lit.</th></tr><tr><td></td><td>3.35</td><td>5</td><td>(9)</td></tr><tr><td></td><td>4.69*</td><td>5</td><td></td></tr></table>	<i>t</i>	<i>A</i>	<i>n</i>	Lit.		3.35	5	(9)		4.69*	5		<b>MoS<sub>2</sub>, Molybdenite (Hex)</b> <table><tr><th><i>t</i></th><th><i>A</i></th><th><i>n</i></th><th>Lit.</th></tr><tr><td>-65</td><td>8.3</td><td>0</td><td>(28)</td></tr><tr><td>+19.5</td><td>7.9</td><td>1</td><td></td></tr><tr><td>102</td><td>2.1</td><td>1</td><td></td></tr><tr><td></td><td>2.6</td><td>0</td><td>(13)</td></tr><tr><td></td><td>1.6</td><td>4</td><td></td></tr></table> <p><math>\alpha = 2.6, \beta = 9, \gamma = 1400</math> <math>\rho = f(v)</math> (31, 46)</p>	<i>t</i>	<i>A</i>	<i>n</i>	Lit.	-65	8.3	0	(28)	+19.5	7.9	1		102	2.1	1			2.6	0	(13)		1.6	4																																									
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<b>NiO (42)</b> <table><tr><td>590</td><td>6.70</td><td>3</td></tr><tr><td>700</td><td>1.02</td><td>3</td></tr><tr><td>1000</td><td>1.44</td><td>2</td></tr><tr><td>1245</td><td>2.4</td><td>1</td></tr></table>	590	6.70	3	700	1.02	3	1000	1.44	2	1245	2.4	1	<b>CaO (21)</b> <table><tr><td>763</td><td>7.25</td><td>8</td></tr><tr><td>1011</td><td>2.06</td><td>7</td></tr><tr><td>1466</td><td>9.6</td><td>2</td></tr></table>	763	7.25	8	1011	2.06	7	1466	9.6	2	<b>Ag<sub>2</sub>S; <math>\rho = f(v)</math> (18)</b> <b>FeS, <math>\alpha</math> Pyrrhotite (Hex)</b> <table><tr><td><math>\parallel c</math></td><td>-73</td><td>6.45</td><td>4</td><td>(26)</td></tr><tr><td><math>\parallel c</math></td><td>0</td><td>5.5</td><td>4</td><td></td></tr><tr><td><math>\parallel c</math></td><td>+18</td><td>5.35</td><td>4</td><td></td></tr><tr><td><math>\parallel c</math></td><td>165</td><td>4.30</td><td>4</td><td></td></tr><tr><td><math>\parallel c</math></td><td>350</td><td>3.87</td><td>4</td><td></td></tr><tr><td><math>\perp c</math></td><td>-68</td><td>5.0</td><td>4</td><td></td></tr><tr><td><math>\perp c</math></td><td>0</td><td>4.4</td><td>4</td><td></td></tr><tr><td><math>\perp c</math></td><td>+19</td><td>4.23</td><td>4</td><td></td></tr><tr><td><math>\perp c</math></td><td>104</td><td>3.55</td><td>4</td><td></td></tr><tr><td><math>\perp c</math></td><td>310</td><td>2.62</td><td>4</td><td></td></tr></table> <p>For <math>\parallel c, \alpha = 4.75, \beta = 2.65, \gamma = 610</math></p>	$\parallel c$	-73	6.45	4	(26)	$\parallel c$	0	5.5	4		$\parallel c$	+18	5.35	4		$\parallel c$	165	4.30	4		$\parallel c$	350	3.87	4		$\perp c$	-68	5.0	4		$\perp c$	0	4.4	4		$\perp c$	+19	4.23	4		$\perp c$	104	3.55	4		$\perp c$	310	2.62	4		<b>FeCb<sub>2</sub>O<sub>6</sub>, Columbite (Orth)</b> <table><tr><td><math>\parallel c</math></td><td>16</td><td>1.95</td><td>8</td><td>(30)</td></tr><tr><td><math>\parallel c</math></td><td>25</td><td>1.39</td><td>8</td><td></td></tr><tr><td><math>\parallel c</math></td><td>32</td><td>1.0</td><td>8</td><td></td></tr></table> <p><b>(NH<sub>4</sub>)<sub>2</sub>Al<sub>2</sub>(SO<sub>4</sub>)<sub>2</sub>·24H<sub>2</sub>O</b> (Iso) purified<table><tr><td>17</td><td>4.9</td><td>14</td><td>(22)</td></tr><tr><td>63</td><td>3.5</td><td>12</td><td></td></tr></table></p>	$\parallel c$	16	1.95	8	(30)	$\parallel c$	25	1.39	8		$\parallel c$	32	1.0	8		17	4.9	14	(22)	63	3.5	12													
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63	3.5	12																																																																																																											
<b>WO<sub>3</sub>, Blue; <math>\rho</math> very low (42)</b> <b>WC (1)</b> <table><tr><td>25</td><td>1.2</td><td>5</td></tr></table>	25	1.2	5	<b>BaO (21)</b> <table><tr><td>307</td><td>1</td><td>6</td></tr><tr><td>355</td><td>1.66</td><td>4</td></tr><tr><td>497</td><td>2.17</td><td>1</td></tr></table>	307	1	6	355	1.66	4	497	2.17	1	<b>FeS, <math>\beta</math> Pyrrhotite (Hex)</b> <table><tr><td><math>\parallel c</math></td><td>350</td><td>3.80</td><td>4</td><td>(26)</td></tr><tr><td><math>\parallel c</math></td><td>445</td><td>3.75</td><td>4</td><td></td></tr><tr><td><math>\perp c</math></td><td>417</td><td>2.5</td><td>4</td><td></td></tr><tr><td><math>\perp c</math></td><td>463</td><td>2.5</td><td>4</td><td></td></tr></table>	$\parallel c$	350	3.80	4	(26)	$\parallel c$	445	3.75	4		$\perp c$	417	2.5	4		$\perp c$	463	2.5	4		<b>CaF<sub>2</sub>, Fluorite (Iso)</b> <table><tr><td>20</td><td>7.9</td><td>17</td><td>(14)</td></tr><tr><td>110</td><td>4.21</td><td>13</td><td></td></tr><tr><td>155</td><td>6.67</td><td>11</td><td></td></tr></table>	20	7.9	17	(14)	110	4.21	13		155	6.67	11																																																															
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<b>W<sub>2</sub>C (1)</b> <table><tr><td>25</td><td>8.1</td><td>5</td></tr><tr><td>1382</td><td>1.05</td><td>4</td></tr><tr><td>1942</td><td>1.25</td><td>4</td></tr></table>	25	8.1	5	1382	1.05	4	1942	1.25	4	<b>Na<sub>2</sub>O<sub>2</sub> (21)</b> <table><tr><td>20</td><td>2.5</td><td>4</td></tr><tr><td>109</td><td>6.0</td><td>3</td></tr><tr><td>284</td><td>1.0</td><td>3</td></tr></table>	20	2.5	4	109	6.0	3	284	1.0	3	<b>FeS<sub>2</sub>, Pyrite† (Iso)</b> <table><tr><td>-78</td><td>2.51</td><td>2</td><td>(23)</td></tr><tr><td>0</td><td>2.40</td><td>2</td><td>(23)</td></tr><tr><td>0</td><td>2.9</td><td>3</td><td>(4)</td></tr><tr><td>+20</td><td>2.40</td><td>2</td><td>(23)</td></tr><tr><td>121</td><td>3.00</td><td>2</td><td>(23)</td></tr><tr><td>340</td><td>3.88</td><td>2</td><td>(23)</td></tr></table> <p><math>\alpha = 3.65, \beta = 3.7, \gamma = 240</math></p>	-78	2.51	2	(23)	0	2.40	2	(23)	0	2.9	3	(4)	+20	2.40	2	(23)	121	3.00	2	(23)	340	3.88	2	(23)	<b>CaCO<sub>3</sub>, Iceland spar (Hex)</b> <table><tr><td><math>\parallel c</math></td><td>20</td><td>1.45</td><td>14</td><td>(22)</td></tr><tr><td><math>\parallel c</math></td><td>20</td><td>9.5</td><td>15</td><td>(14)</td></tr><tr><td><math>\parallel c</math></td><td>100</td><td>6.25</td><td>10</td><td>(22)</td></tr><tr><td><math>\parallel c</math></td><td>100</td><td>2.37</td><td>12</td><td>(14)</td></tr><tr><td><math>\perp c</math></td><td>20</td><td>5.5</td><td>14</td><td>(14)</td></tr><tr><td><math>\perp c</math></td><td>27.8</td><td>9.9</td><td>22</td><td>(38)</td></tr><tr><td><math>\perp c</math></td><td>100</td><td>4.95</td><td>11</td><td>(14)</td></tr></table>	$\parallel c$	20	1.45	14	(22)	$\parallel c$	20	9.5	15	(14)	$\parallel c$	100	6.25	10	(22)	$\parallel c$	100	2.37	12	(14)	$\perp c$	20	5.5	14	(14)	$\perp c$	27.8	9.9	22	(38)	$\perp c$	100	4.95	11	(14)																													
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<b>U<sub>3</sub>O<sub>8</sub>, <math>\rho</math> very low (42)</b> <b>CeO<sub>2</sub> (42)</b> <table><tr><td>830</td><td>2.24</td><td>3</td></tr><tr><td>1000</td><td>2.13</td><td>2</td></tr><tr><td>1210</td><td>1.87</td><td>1</td></tr></table>	830	2.24	3	1000	2.13	2	1210	1.87	1	<p>* For B, <math>\rho</math> varies with emf (29) † <math>\rho_t = \rho_0 e^{\lambda t}</math>; for I, <math>\lambda = -0.126</math> ‡ Variation with pressure (11) Unit of <math>P = 1000 \text{ kg/cm}^2</math></p> <table><tr><th><i>P</i></th><th><math>\rho/\rho_0</math></th><th></th></tr><tr><th></th><th>0°</th><th>50°</th><th>100°</th><th></th></tr><tr><td>0</td><td>1.000</td><td>0.662</td><td>0.421</td><td></td></tr><tr><td>1</td><td>0.796</td><td>0.521</td><td>0.323</td><td></td></tr><tr><td>2</td><td>0.643</td><td>0.406</td><td>0.250</td><td></td></tr><tr><td>4</td><td>0.372</td><td>0.239</td><td>0.1517</td><td></td></tr><tr><td>8</td><td>0.1079</td><td>0.0766</td><td>0.0542</td><td></td></tr><tr><td>12</td><td>0.0297</td><td>0.0238</td><td>0.0209</td><td></td></tr></table> <p>§ Electrolysed crystalline plates.    Carbonized W filaments.</p>	<i>P</i>	$\rho/\rho_0$			0°	50°	100°		0	1.000	0.662	0.421		1	0.796	0.521	0.323		2	0.643	0.406	0.250		4	0.372	0.239	0.1517		8	0.1079	0.0766	0.0542		12	0.0297	0.0238	0.0209		<b>CaCO<sub>3</sub>, Marble</b> <table><tr><td>22</td><td>5</td><td>9</td><td>(15)</td></tr><tr><td>22</td><td>1</td><td>9</td><td></td></tr></table>	22	5	9	(15)	22	1	9		<b>BaSO<sub>4</sub>, Barite (Orth)</b> <table><tr><td><math>\parallel b</math></td><td>726</td><td>1.5</td><td>5</td><td>(26)</td></tr><tr><td><math>\parallel b</math></td><td>963</td><td>1.0</td><td>4</td><td></td></tr></table> <p>Polarization emf = 1 to 1.4 volt</p>	$\parallel b$	726	1.5	5	(26)	$\parallel b$	963	1.0	4																																										
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<b>C, Diamond (Iso); see Table 1</b> <b>SiO<sub>2</sub>, Quartz (Hex)</b> <table><tr><td><math>\parallel c</math></td><td>20</td><td>1.18</td><td>14</td><td>(14)</td></tr><tr><td><math>\parallel c</math></td><td>26.5</td><td>2.0</td><td>22</td><td>(37)</td></tr><tr><td><math>\parallel c</math></td><td>100</td><td>8.18</td><td>11</td><td>(14)</td></tr><tr><td><math>\perp c</math></td><td>20</td><td>3.27</td><td>16</td><td>(14)</td></tr><tr><td><math>\perp c</math></td><td>26.4</td><td>4.3</td><td>24</td><td>(37)</td></tr><tr><td><math>\perp c</math></td><td>100</td><td>1.34</td><td>15</td><td>(14)</td></tr><tr><td><math>\parallel c</math></td><td>25</td><td>5</td><td>16</td><td>(49)</td></tr></table> <p>See also p. 341</p>	$\parallel c$	20	1.18	14	(14)	$\parallel c$	26.5	2.0	22	(37)	$\parallel c$	100	8.18	11	(14)	$\perp c$	20	3.27	16	(14)	$\perp c$	26.4	4.3	24	(37)	$\perp c$	100	1.34	15	(14)	$\parallel c$	25	5	16	(49)	<b>PbS, Galena (Iso)</b> <table><tr><td>-180</td><td>5.9</td><td>3</td><td>(25)</td></tr><tr><td>0</td><td>2.42</td><td>3</td><td></td></tr><tr><td>+20</td><td>2.65</td><td>3</td><td></td></tr><tr><td>340</td><td>6.06</td><td>3</td><td></td></tr></table> <p><math>a = 5.24, \text{ if } -180^\circ \leq t \leq 150^\circ</math></p>	-180	5.9	3	(25)	0	2.42	3		+20	2.65	3		340	6.06	3		<b>Fe<sub>2</sub>O<sub>3</sub>, Magnetite† (Iso)</b> <table><tr><td>-61</td><td>5.1</td><td>2</td><td>(26)</td></tr><tr><td>+21</td><td>3.6</td><td>2</td><td></td></tr><tr><td>111</td><td>2.88</td><td>2</td><td></td></tr><tr><td>190</td><td>2.77</td><td>2</td><td></td></tr><tr><td>(u)</td><td>19</td><td>1.98</td><td>0</td><td>(30)</td></tr><tr><td>(v)</td><td>17</td><td>7.4</td><td>1</td><td></td></tr><tr><td>(w)</td><td>25</td><td>1.37</td><td>1</td><td></td></tr><tr><td>(x)</td><td>7</td><td>6.0</td><td>1</td><td></td></tr><tr><td>(y)</td><td>10</td><td>2.2</td><td>1</td><td></td></tr></table>	-61	5.1	2	(26)	+21	3.6	2		111	2.88	2		190	2.77	2		(u)	19	1.98	0	(30)	(v)	17	7.4	1		(w)	25	1.37	1		(x)	7	6.0	1		(y)	10	2.2	1		<b>NaBr, (Iso)</b> <table><tr><td>440</td><td>1.51</td><td>6</td><td>(41)</td></tr><tr><td>600</td><td>3.62</td><td>4</td><td></td></tr><tr><td>740</td><td>4.07</td><td>3</td><td></td></tr></table>	440	1.51	6	(41)	600	3.62	4		740	4.07	3			
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<b>CuSO<sub>4</sub>·5H<sub>2</sub>O (purified) (Tri)</b> <table><tr><td>17</td><td>6.7</td><td>14</td><td>(22)</td></tr></table>	17	6.7	14	(22)	<b>Cu<sub>3</sub>As, Algodonite (Orth)</b> <table><tr><td></td><td>4.15</td><td>5</td><td>(9)</td></tr><tr><td></td><td>6.34*</td><td>5</td><td></td></tr></table>		4.15	5	(9)		6.34*	5		<b>NaNO<sub>3</sub>, (Hex) rhombohedral</b> <table><tr><td>240</td><td>6.25</td><td>6</td><td>(41)</td></tr><tr><td>250</td><td>5.27</td><td>6</td><td></td></tr><tr><td>300</td><td>4.54</td><td>5</td><td></td></tr><tr><td>310</td><td>1.82</td><td>5</td><td></td></tr></table>	240	6.25	6	(41)	250	5.27	6		300	4.54	5		310	1.82	5		<b>KCl, (Iso)</b> <table><tr><td>520</td><td>4.37</td><td>6</td><td>(41)</td></tr><tr><td>600</td><td>5.58</td><td>5</td><td></td></tr><tr><td>760</td><td>8.7</td><td>3</td><td></td></tr></table>	520	4.37	6	(41)	600	5.58	5		760	8.7	3																																																																			
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## KCl.KBr, Mixed crystal

$t$	$A$	$n$	Lit.
520	2.50	6	(41)
640	1.20	5	
720	1.17	4	

\* After fusing.

† For effect of pressure, v. Table 5.

‡ Magnetite:  $\Delta = (\rho - \rho_p)/\rho$ , where  $\rho_p$  = value of  $\rho$  for a longitudinal compression of 887 kg/cm<sup>2</sup>.

	Source	$a$	100 $\Delta$
(u)	New York	6.8	0.52
(c)	New York	6.1	2.64 (slaty)

KAlSi<sub>3</sub>O<sub>8</sub>, Orthoclase (Mon)

	$t$	$A$	$n$	Lit.
b	800	8.5	3	(26)
b	1400	0.80	3	

## ‡ Magnetite.—(Continued)

	Source	$a$	100 $\Delta$
(w)	Russia	5.5	0.40
(x)	Arkansas	4.0	0.45
(y)	Tilly Foster, New York	7.9	0.15

§  $\log_{10} \rho = 4780/T - 2.17$ .

|| Perpendicular to rhombohedral face (1011).

TABLE 3.—ELECTRICAL RESISTIVITY ( $\rho$ ) OF NERNST AND AUER MIXTURES CONTAINING RARE EARTHS (48)For laboratory construction of Nernst filaments, v. (20). Unit of  $\rho = 1$  ohm-cm;  $t$  = centigrade temperature, °C;  $\rho = A \times 10^n$ 

Mixture	$t$	$A$	$n$
Nernst (oxides of Zr, Y, Er).....	230	2.72	6
	303	1.92	5
	400	1.02	4
	571	3.98	2
	922	1.29	1
	1252	3.49	0
	745	2.19	4
Auer (oxides of Ce, Th).....	890	7.85	3
	1068	1.99	3
	1211	6.40	2

TABLE 4.—RESISTIVITY OF MIXED LIQUIDS SUITABLE FOR MAKING HIGH RESISTANCES: MIXTURES OF XYLENE AND ETHYL ALCOHOL (12)

 $P = \% C_2H_5OH$  by weight;  $\rho = A \times 10^n$ ;  $\alpha_{15} = \left(\frac{1}{\rho} \frac{d\rho}{dt}\right)_{15^\circ C}$   
Unit of  $\rho = 1$  ohm cm; of  $P = 1\%$ ; Temperature = 25.6°C

$P$ .....	100	25	20	18	16	14	12	10
$A$ .....	1.44	2.24	1.00	1.88	3.56	6.94	1.73	5.95
$n$ .....	5	6	7	7	7	7	8	8

$P$ .....	9	8	7	6	5	4	0
$A$ .....	1.18	2.66	6.25	1.69	4.72	1.41	>1
$n$ .....	9	9	9	10	10	11	15

 $P = 25$ ,  $\alpha_{15} = 0.0117$ ;  $P = 10.2$ ,  $\alpha_{15} = 0.0168$ ;  $P = 5.5$ ,  $\alpha_{15} = 0.0124$ .

TABLE 5.—EFFECT OF PRESSURE UPON RESISTIVITY OF POOR CONDUCTORS (4)

If  $\Delta\rho = \rho_p - \rho_1$ , where  $\rho_p$ ,  $\rho_1$  = volume resistivity when hydrostatic pressure =  $p$ , = 1, respectively; then

$$a \times 10^{-6} = \frac{\Delta\rho}{\rho_1(p-1)} \left(1 + \frac{1}{2} \frac{\Delta\rho}{\rho_1}\right).$$

TABLE 5.—(Continued)

 $\rho_1 = A \times 10^n$ ; ||c,  $\perp c$  denote that the current is ||,  $\perp$  to the crystallographic  $c$ -axis. Unit of  $\rho = 1$  ohm cm; of  $p = 1$  atmosphere; temperature = 0°C.

Substance		$A$	$n$	$p$	$-a$
FeS <sub>2</sub>	Pyrite.....	2.9	3	2550	23.1
Fe <sub>2</sub> O <sub>3</sub>	Specularite.....	c 8.2	1	2510	8.2
		$\perp c$ 4.2	1	2520	6.8
Fe <sub>3</sub> O <sub>4</sub>	Magnetite.....	v. Note, ‡ Table 2			
P	Phosphorus.....	v. Note, ‡ Table 1			

TABLE 6.—SURFACE RESISTIVITY: EFFECT OF HUMIDITY OF AIR (39)

The ability to maintain a high resistance when surrounded by moist air increases in the order glass, ebonite, amber, sulfur, paraffin.  $H$  = relative humidity;  $R$  = resistance of a 2 cm length of a polished amber cylinder 0.5 cm in diameter; observations made in order of the entries in table. (v.s.) = very small. Unit of  $R = 10^{12}$  ohm; of  $H = 1\%$ . Room temperature.

$H$ .....	77.5	80	82	85	86	88	90	93	82	96	82	99	82	100	82
$R$ .....	409	294	204	98	65	40	20	4	198	1.6	94	0.4	42	(v.s.)	1.4

## LITERATURE

(For a key to the periodicals see end of volume)

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ELECTRICAL CONDUCTIVITY OF FLAMES

HAROLD A. WILSON

Nearly all data pertaining to the electrical conductivity of flames are purely relative and depend upon the particular flame used; as the temperature of the flame is, in general, not known, the data are not reproducible. Typical data are given in Tables 1 and 2. For additional data and details, the original sources listed in the bibliography should be consulted. See also *Handbuch der Experimental Physik*, Vol. XIII, Part I, Elektrischen Eigenschaften der Flamme, A. Becker, 1929.

TABLE 1.—ELECTRICAL PROPERTIES OF BUNSEN FLAME  
Approximately 2000°K

Property	Value	Lit.
Velocity, negative ions (electrons)	2600 cm sec <sup>-1</sup> per volt cm <sup>-1</sup>	(4, 6, 18, 31, 32, 36, 38, 39)
Velocity, positive ions	1 or 2 cm sec <sup>-1</sup> per volt cm <sup>-1</sup>	(1, 2, 3, 6, 18, 29, 32, 33)
Resistivity	4 × 10 <sup>5</sup> ohm-cm	(4, 32, 38)

TABLE 2.—ELECTRICAL PROPERTIES OF METALLIC VAPORS IN BUNSEN FLAME  
Approximately 2000°K

Property	Li	Na	K	Rb	Cs	Unit	Lit.
Conductivity, equal atomic concentrations.	0.5	1	7	12	21	Na = 1	(6, 18, 32, 34, 38, 39)
Atomic concentration, equal conductivities.	1700	440	9	4	1	Cs = 1	(6, 18, 32, 34)
Atoms ionized, concentration very low	1.6	58	69	91		%	(4, 26, 34)

TABLE 2.—(Continued)

Property	Lit.
Ionization of alkali vapors approximately agrees with that calculated by Saha's theory	(4, 26, 38, 39)
Hall effect: $Y/X = 2.45 \times 10^{-4}H$ ; $X$ = longitudinal electric field, $Y$ = transverse electric field due to Hall effect, $H$ = intensity of magnetic field (in gauss)	(11, 12, 13, 18, 33, 40, 41)

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(For a key to the periodicals see end of volume)

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ELECTRICAL RESISTIVITY OF ALLOYS, AMALGAMS, AND COMMERCIAL METALS

C. V. DRYSDALE<sup>1</sup>

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Symbols.	Symboles.	Symbole.	Simboli.	157
Named alloys.	Noms usuels des alliages.	Gebräuchliche Namen der Legierungen.	Nomi usuali delle leghe.	159
Resistivity of alloys, amalgams, and commercial metals.	Résistivité des alliages, des amalgames, et des métaux commerciaux.	Elektrischer Widerstand der Legierungen, der Amalgame und der Handelsmetalle.	Resistività delle leghe, delle amalgame e dei metalli commerciali.	159
Resistivity of non-mercuric alloys near and above their normal melting point.	Résistivité des alliages non-mercuriques près et au-dessus de leurs points de fusion.	Widerst. d. Hg-freier Legierungen: r. Nähe oder oberhalb ihres Schmelzpunktes.	Resistività delle leghe non mercuriche vicino e sopra di loro punti di fusione.	196
Effect of heat treatment upon resistivity of steels.	Influence du traitement thermique sur la résistivité des aciers.	Einfluss der Wärmebehandlung auf den Widerstand der Stähle.	Influenza del trattamento termico sulla resistività dei acciai.	200
Additional references.	Références bibliographiques additionnelles	Nachträgliches Literaturverzeichnis.	Indicazioni bibliografiche addizionale.	201

In general, this report does not include the effect of either a magnetic field or of illumination upon the resistivity, nor the resistivity of single crystals; the resistivities of pure metals enter only incidentally as terminal members in series of alloys; and only such commercial metals are considered as are of interest to electricians.

With certain obvious exceptions, all data pertaining to the resistivity and its variation with temperature, heat treatment, composition of the alloy, etc. are given in Table 2.

Alloys that have distinctive names and are of special interest to

<sup>1</sup> Assisted by Messrs. A. C. Jolley and S. J. Willis.

electricians are listed alphabetically in Table 1 which serves as an index to them; there the approximate ranges in resistivity and temperature coefficient are given.

**Caution.**—The composition and electrical properties of alloys sold under manufacturers' trade names are to a greater or less extent under the control of the manufacturer. The reader cannot, therefore, assume that such an alloy obtained from a manufacturer will have the properties shown below. The data given in this section have been compiled from various sources and for named alloys may be subject to change. For more explicit information the manufacturer should always be consulted.



## SYMBOLS

A	Annealed.
A <sub>t</sub>	Annealed from $t$ , °C.
a, b	Coefficients in $(\rho_t)_{Hg}/(\rho_t)_{Amalgam} = a + bt(10)^{-6}$ .
C	Concentration; % by weight of alloying element in total weight of alloy.
C <sub>t</sub>	Concentration of total impurities.
Cst	Cast.
D	$D = 100d\rho/dt$ , or $D = 100dR/dt$ . When inserted in a series of values of $t$ or of $\rho_t$ , the observations show that it applies throughout the range bounded by the adjacent values of $t$ or of $\rho_t$ .
D <sub>t</sub>	Value of $D$ when the temperature exceeds $t$ , °C.
D	Drawn (wire).
Dd	Drawn, hard.
Dr	Temper drawn by reheating to $t_{Dr}$ , °C.
e	Coefficients in $\rho = \rho_0 + e_1C_1 + e_2C_2$ .
elec	Electrolytic.
F	Forged.
H <sub>t</sub>	Hardened at $t$ , °C (cf. Q).
Hm	Hammered.
l	Liquid.
k	Per cent decrease in conductivity per 1 % concentration: $\rho_c - \rho_{c=0} = kC\rho_c/100 \equiv \delta_c$ .
N	Normal, normalized (cooled in still air).
O	Before specific heat treatment.
Q	Quenched.
Q <sub>t</sub>	Quenched from $t$ , °C.
R	Relative resistivity; frequently the unit is unknown.
R <sub>c</sub>	Rolled cold.
s	Solid.
Sat.	Saturated.
Tp	Tempered.
Tp <sub>t</sub>	Tempered at $t$ , °C.
t	Temperature, °C.
t <sub>A</sub>	Annealing temperature.
t <sub>Dr</sub>	Drawing temperature; temperature to which the quenched specimen was reheated.
t <sub>m</sub>	Melting temperature.
t <sub>R</sub>	Room temperature.
t <sub>s</sub>	Solidifying temperature.
t <sub>TP</sub>	Tempering temperature.
tr.	Trace; very small amount.
vac	In vacuum.
Wk <sub>c</sub>	Worked cold.
$\alpha, \beta, \gamma$	Coefficients in $\rho_t = \rho_0[1 + \alpha_t(t - t')10^{-3} + \beta_t(t - t')^2 \times 10^{-6} + \gamma_t(t - t')^3 10^{-9}]$ ; and similarly for $R_t$ . Unless another value is indicated, $t'$ is 0. When only $\alpha$ or $\alpha$ and $\beta$ are given, the others are zero.
$\delta_f$	Per cent decrease in $\rho$ on fusion; $\delta_f = 100(\rho_l - \rho_s)/\rho_l$ .
$\delta_c$	Increase in $\rho$ due to adding $C\%$ of second metal; see k.
$\Delta_H$	Per cent increase in $\rho$ due to cold hardening; $\Delta_H = 100 \times (\rho_H - \rho_A)/\rho_A$ .
$\Delta_t$	Mean temperature coefficient between 0 and $t$ , °C; $\Delta_t = 1000(\rho_t - \rho_0)/\rho_0 t$ .
$t_1 \Delta_{t_2}$	Mean temperature coefficient, based on $\rho_0$ , between $t_1$ and $t_2$ ; $t_1 \Delta_{t_2} = 1000(\rho_{t_2} - \rho_{t_1})/\rho_0(t_2 - t_1)$ .
$\rho$	Resistivity; specific resistance.
$\rho_A$	Resistivity of annealed specimen. Similarly for $\rho_{TP}$ , $\rho_{Hm}$ , etc.
$\rho_t$	Resistivity at $t$ , °C.

## SYMBLES

A	Recuit.
A <sub>t</sub>	Recuit de $t$ , °C.
a, b	Coefficients dans l'expression $(\rho_t)_{Hg}/(\rho_t)_{Amalgam} = a + bt(10)^{-6}$ .
C	Concentration; % en poids d'élément d'alliage en poids total d'alliage.
C <sub>t</sub>	Concentration des impuretés totales.
Cst	Coulé.
D	$D = 100d\rho/dt$ , ou $D = 100dR/dt$ . Quand celui-ci est introduit dans une série de valeurs de $t$ ou de $\rho_t$ , les observations montrent qu'il est applicable dans tout l'intervalle compris entre valeurs successives de $t$ ou de $\rho_t$ .
D <sub>t</sub>	Valeur de $D$ quand la température est au-dessus de $t$ , °C.
D	Étiré (Fil).
Dd	Étiré, dur.
Dr	Revenu détruit par rechauffage à $t_{Dr}$ , °C.
e	Coefficients dans l'expression: $\rho = \rho_0 + e_1C_1 + e_2C_2$ .
elec	Électrolytique.
F	Forgé.
H <sub>t</sub>	Durci à $t$ , °C (cf. Q).
Hm	Martelé.
l	Liquide.
k	Diminution de conductibilité en pourcent pour 1 % de concentration: $\rho_c - \rho_{c=0} = kC\rho_c/100 \equiv \delta_c$ .
N	Normal, normalisé (refroidi dans l'air calme).
O	Avant le traitement thermique spécifique.
Q	Trempé.
Q <sub>t</sub>	Trempé de $t$ , °C.
R	Résistivité relative; fréquemment l'unité de celle-ci n'est pas connue.
R <sub>c</sub>	Laminé, froid.
s	Solide.
Sat.	Saturé.
Tp	Revenu.
Tp <sub>t</sub>	Revenu à $t$ , °C.
t	Température, °C.
t <sub>A</sub>	Température de recuit.
t <sub>Dr</sub>	Température d'étirage; la température à laquelle l'échantillon trempé a été rechauffé.
t <sub>m</sub>	Température de fusion.
t <sub>R</sub>	Température de la chambre.
t <sub>s</sub>	Température de solidification.
t <sub>TP</sub>	Température de revenu.
tr.	Trace; très petite quantité.
vac	Dans le vide.
Wk <sub>c</sub>	Travaillé, froid.
$\alpha, \beta, \gamma$	Coefficients dans l'expression: $\rho_t = \rho_0[1 + \alpha_t(t - t') \times 10^{-3} + \beta_t(t - t')^2 10^{-6} + \gamma_t(t - t')^3 10^{-9}]$ ; et de même pour $R_t$ . À moins d'une autre indication, $t'$ est 0. Quand on ne donne que $\alpha$ ou $\alpha$ et $\beta$ , les autres coefficients sont égaux à zéro.
$\delta_f$	Diminution en pourcent de $\rho$ lors de la fusion: $\delta_f = 100(\rho_l - \rho_s)/\rho_l$ .
$\delta_c$	Augmentation de $\rho$ due à l'addition de $C\%$ d'un deuxième métal; voir k.
$\Delta_H$	Augmentation en pourcent due au durcissement à froid: $\Delta_H = 100(\rho_H - \rho_A)/\rho_A$ .
$\Delta_t$	Coefficient moyen de température entre 0 et $t$ , °C; $\Delta_t = 1000(\rho_t - \rho_0)/\rho_0 t$ .
$t_1 \Delta_{t_2}$	Coefficient moyen de température basé sur $\rho_0$ entre $t_1$ et $t_2$ ; $t_1 \Delta_{t_2} = 1000(\rho_{t_2} - \rho_{t_1})/\rho_0(t_2 - t_1)$ .
$\rho$	Résistivité; résistance spécifique.
$\rho_A$	Résistivité de l'échantillon recuit. De même pour $\rho_{TP}$ , $\rho_{Hm}$ , etc.
$\rho_t$	Résistivité à $t$ , °C.



## ZEICHEN

A	Ausgeglüht.
A <sub>t</sub>	Ausgeglüht von $t$ , °C.
a, b	Koeffizient von $(\rho_t)_{Hg}/(\rho_t)_{Amalgam} = a + bt(10)^{-6}$ .
C	Konzentration; % in Mass von Legierungs Element in gesammter Mass von Legierung.
C <sub>t</sub>	Konzentration sämtlicher Verunreinigungen.
Cst	Gegossen.
D	$D = 100d\rho/dt$ oder $D = 100dR/dt$ . Setzt man eine Reihe von Werten für $t$ oder $\rho_t$ ein, so zeigen die Beobachtungen, dass der Wert ( $D$ ) in dem durch die Nachbarwerte von $t$ oder $\rho_t$ begrenzten Bereiche Gültigkeit hat.
D <sub>t</sub>	Werte von $D$ wenn die Temperatur grösser ist als $t$ , °C.
D	Gezogen (Draht).
Dd	Hart gezogen.
Dr	Angelassenes Stück gezogen durch Wiedererwärmung auf $t_{Dr}$ , °C.
e	Koeffizient von $\rho = \rho_0 + e_1C_1 + e_2C_2$ .
elec	Elektrolytisch.
F	Geschmiedet.
H <sub>t</sub>	Gehärtet bei $t$ , °C (cf. Q).
Hm	Gehämmert.
l	Flüssigkeit.
k	Abnahme in % der Leitfähigkeit pro 1 % der Konzentration: $\rho_c - \rho_{c=0} = kC\rho_c/100 \equiv \delta_c$ .
N	Normal, Normalisiert (in ruhiger Luft gekühlt).
O	Vor der spezifischen Wärmebehandlung.
Q	Abgeschreckt.
Q <sub>t</sub>	Abgeschreckt von $t$ , °C.
R	Relativer Widerstand dessen Einheit häufig unbekannt ist.
R <sub>c</sub>	Kalt gewalzt.
s	Feste Stoffe.
Sat.	Gesättigt.
Tp	Angelassen.
Tp <sub>t</sub>	Angelassen bei $t$ , °C.
t	Temperatur, °C.
t <sub>A</sub>	Temperatur des Ausglühens.
t <sub>Dr</sub>	Temperatur beim Ziehen; Temperatur auf welche die abgeschreckte Probe wiederholt erhitzt wurde.
t <sub>m</sub>	Schmelztemperatur.
t <sub>R</sub>	Zimmer Temperatur.
t <sub>s</sub>	Erstarrungstemperatur.
t <sub>TD</sub>	Temperatur beim Anlassen.
tr.	Spur; sehr kleiner Betrag.
vac	In Luftleere.
Wk <sub>c</sub>	Kalt geschmiedet.
$\alpha, \beta, \gamma$	Koeffizient von $\rho_t = \rho_0[1 + \alpha_t(t - t')10^{-3} + \beta_t(t - t')^210^{-6} + \gamma_t(t - t')^310^{-9}]$ ; in gleicher Weise für $R_t$ . Wenn nicht ein anderer Wert angegeben ist, beträgt $t' = 0$ . Sind nur $\alpha$ oder $\alpha$ und $\beta$ angegeben so sind die anderen Null.
$\delta_f$	Abnahme in % von $\rho$ beim Schmelzen; $\delta_f = 100(\rho_l - \rho_s)/\rho_l$ .
$\delta_c$	Zunahme von $\rho$ beim Zusatz von $C\%$ des zweiten Metalles; siehe k.
$\Delta_H$	Zunahme in % von $\rho$ durch Kalthärtung; $\Delta_H = 100(\rho_H - \rho_A)/\rho_A$ .
$\Delta_t$	Mittlerer Temperaturkoeffizient zwischen 0 und $t$ , °C; $\Delta_t = 1000(\rho_t - \rho_0)/\rho_0 t$ .
$_{11}\Delta_{12}$	Mittlerer Temperaturkoeffizient, auf Grund von $\rho_0$ zwischen $t_1$ und $t_2$ ; $_{11}\Delta_{12} = 1000(\rho_2 - \rho_1)/\rho_0(t_2 - t_1)$ .
$\rho$	Widerstand; spezifischer Widerstand.
$\rho_A$	Widerstand der ausgeglühten Probe. In gleicher Weise für $\rho_{TD}$ , $\rho_{Hm}$ , u. s. w.
$\rho_t$	Widerstand bei $t$ , °C.

## SIMBOLI

A	Ricotto.
A <sub>t</sub>	Ricotto a $t$ , °C.
a, b	Coefficienti in $(\rho_t)_{Hg}/(\rho_t)_{Amalgam} = a + bt(10)^{-6}$ .
C	Concentrazioni; % in peso dell'elemento in peso totale delle leghe.
C <sub>t</sub>	Concentrazioni delle impurezze totali.
Cst	Gettato.
D	$D = 100d\rho/dt$ , o $D = 100dR/dt$ . Quando inserito in una serie di valori di $t$ o di $\rho_t$ le osservazioni mostrano che si applica per tutto il campo limitato dai valori adiacenti di $t$ o di $\rho_t$ .
D <sub>t</sub>	Valore di $D$ quando la temperatura è al di sopra di $t$ , °C.
D	Trafilato.
Dd	Trafilato, duro.
Dr	Rinvenuto per riscaldamento a $t_{Dr}$ , °C.
e	Coefficiente in $\rho = \rho_0 + e_1C_1 + e_2C_2$ .
elec	Elettrolitico.
F	Forgiato.
H <sub>t</sub>	Indurito a $t$ , °C (cf. Q).
Hm	Martellato.
l	Liquido.
k	Diminuzione per cento della conduttività per 1 % di concentrazione: $\rho_c - \rho_{c=0} = kC\rho_c/100 \equiv \delta_c$ .
N	Normale, normalizzato (raffreddato all'aria calma).
O	Prima del trattamento termico specifico.
Q	Temprato.
Q <sub>t</sub>	Temprato da $t$ , °C.
R	Resistività relativa; spesso l'unità è sconosciuta.
R <sub>c</sub>	Laminato a freddo.
s	Solido.
Sat.	Saturato.
Tp	Rinvenuto.
Tp <sub>t</sub>	Rinvenuto a $t$ , °C.
t	Temperatura, °C.
t <sub>A</sub>	Temperatura di ricottura.
t <sub>Dr</sub>	Temperatura di rinvenimento; temperatura alla quale il campione temprato veniva riscaldato.
t <sub>m</sub>	Temperatura di fusione.
t <sub>R</sub>	Temperatura ambiente.
t <sub>s</sub>	Temperatura di solidificazione.
t <sub>TD</sub>	Temperatura di rinvenimento.
tr.	Traccia; piccolissima quantità.
vac	Nel vuoto.
Wk <sub>c</sub>	Lavorato a freddo.
$\alpha, \beta, \gamma$	Coefficienti in $\rho_t = \rho_0[1 + \alpha_t(t - t')10^{-3} + \beta_t(t - t')^2 \times 10^{-6} + \gamma_t(t - t')^310^{-9}]$ ; e similmente per $R_t$ . A meno che sia indicato un altro valore $t'$ è 0. Quando sono dati $\alpha$ o $\alpha$ e $\beta$ , gli altri sono zero.
$\delta_f$	Diminuzione per cento in $\rho$ nella fusione; $\delta_f = 100(\rho_l - \rho_s)/\rho_l$ .
$\delta_c$	Aumento in $\rho$ dovuto all'aggiunta di $C\%$ del secondo metallo; vedi k.
$\Delta_H$	Aumento per cento in $\rho$ dovuto all'indurimento prodotto dalla lavorazione a freddo; $\Delta_H = 100(\rho_H - \rho_A)/\rho_A$ .
$\Delta_t$	Coefficiente di temperatura media tra 0 e $t$ , °C; $\Delta_t = 1000(\rho_t - \rho_0)/\rho_0 t$ .
$_{11}\Delta_{12}$	Coefficiente di temperatura media basato su $\rho_0$ , tra $t_1$ e $t_2$ ; $_{11}\Delta_{12} = 1000(\rho_{12} - \rho_{11})/\rho_0(t_2 - t_1)$ .
$\rho$	Resistività; resistenza specifica.
$\rho_A$	Resistività del campione ricotto. Similmente per $\rho_{TD}$ , $\rho_{Hm}$ , ecc.
$\rho_t$	Resistività a $t$ , °C.



TABLE 1. NAMED ALLOYS

The following list contains primarily those alloys that are electrically interesting. More exact and detailed information will be found at the pages indicated.

Unit of  $\rho$  = 1 microhm-cm =  $10^{-6}$  ohm-cm; of  $\alpha$  = 0.1% per 1 °C

Name	$\rho$	$\alpha$	Page
Advance.....	48-49	0.01-0.02	169, 170
Alumel.....	33.3	1.2	194
Aluminium bronze.....	3-13	0.3-3.8	162
Aluminium bronze.....	15	0.64	167
American nickel.....	73	1-5	196
Argentan.....	42		171
Beacon alloy.....	60-80	0.7	196
Brass.....	5-7	1.4-2	172
Bronze.....	13-18	0.5	171, 172
Calido.....	110	0.12	194
Calorite.....	110		194
Cast iron.....	57-114		188
Cementite.....	45		182
Chromax.....	(Nichrome IV)		193,
Chromel.....	70-110	0.11-0.54	193, 194
Cimet.....	17-44		178
Climax.....	87	0.67	185
Comet.....	95.6	0.34	185
Constantan.....	47-51	-0.04-(+0.01)	169, 170
Copel.....	49.5	Nil.	169
Dowmetal.....	13-17		162
Duralumin.....	3.35		162
Duriron.....	63	4.9	188
Eureka.....	(Constantan)		169
Eutectoid.....	20		178
Excello.....	92	0.16	193, 194
Excelsior.....	6-80	0.95-1.4	169
Extra Prima.....	29.4	0.28	196
Fagersta steel.....	12.6-21		182
Ferrite.....	9.5		182
Ferro-nickel.....	28	2.1	185
Ferrozoid.....	84		196
Ferry.....	47		196
German silver.....	17-41	0.04-0.38	170, 171
Gysinge steel.....	10-50		182
Hadfield Mn-steel.....	29-67	1.2-2.0	182, 185
Ia-Ia.....	47-51	-0.04-(+0.03)	169
Ideal.....	49	0.005	169
Invar.....	75	2	185
Karma.....	103	0.1	193, 194
Kromore.....	(Nichrome III)		193, 194
Krupp.....	85	0.7	196
Kruppin.....	83-85	0.7-1.3	185
Lipowitz alloy.....	47-53	2.7	165, 197
Lucero.....	46	0.76	170
Magno.....	20	0.005	194
Maillechort.....	(German silver)		171
Mangaloy.....	107	0.073	196
Manganese nickel.....	15		194
Manganin.....	34-100	-0.03-(+0.02)	168
Monel.....	42.5-45	0.02-2.0	170
New metal.....	51	-0.038	196
New silver.....	(German silver)		170, 171
Nichrome.....	110	0.4-0.03	193
Nichrome II.....	109-111	0.15	193
Nichrome III.....	90-97	0.05-0.19	193
Nichrome IV.....	98-103	0.18	193
Nickel silver, 18%.....	30-33	0.3	171

Name	$\rho$	$\alpha$	Page
Nickeline.....	27-45	0.02-0.34	171
No. 3 alloy.....	114		193
No. 4 alloy.....	103		185
No. 141 alloy.....	22-30		194
No. 193 alloy*.....	87-96	0.014-0.8	185, 186
Patent nickel.....	33-34	0.19-0.21	169, 170
Phosphor bronze†.....	2-6	3-4	172
Platinite.....	45	3	185
Platinoid.....	34-41	0.32-0.25	171
Rayo.....	96	0.102	171, 194
Resista.....	76	1.1	196
Resistin.....	50.2		168
Rheostatine.....	48	0.25	169
Rheostene.....	77	1.2	196
Rheotan.....	48-52	0.24-0.41	171
Rose's alloy.....	64	1.8	196
Silicon bronze†.....	2-4	2.3-3.8	172
Silverine.....	2	2.85	169
Spiegeleisen.....	105		182, 188
Superior.....	81-87	0.8-1.1	196
Swedish iron.....	20	1.2	174
Tarnac.....	41	0.025	196
Therlo.....	46.5	0.01	168
Tophet.....	107		194
Vestalin.....	83-85	0.7-1.3	185
Welding iron.....	18	6	175
Wood's metal.....	51.7	2.9	196

\* Driver-Harris Co.

† Telegraph and telephone wires.

TABLE 2.—RESISTIVITY OF ALLOYS, AMALGAMS, AND COMMERCIAL METALS

(For effect of small amounts of impurities in "pure" metals, *v.* p. 135; for general trend of the variations of resistivity with composition or with temperature, *v.* figures, p. 202; for resistivity of non-mercuric alloys near and above the melting point, *v.* Table 3.)

Arrangement of alloys is, in general, alphabetical by "type formula," which consists in each case of the chemical symbols of the essential constituents written in descending order of the amounts of the constituents except that for a steel, C is always written last. In certain cases, alloys of different type formulae are combined in a single group; in such cases, the type formula for the group contains the symbols of all the constituents of the group, and those that are not common to every member of the group are enclosed in ( ). Thus Al-Fe-(Cu, Mn, Si) indicates that Al and Fe are common to every member of the group, but neither Cu, Mn, nor Si is common to all. If the concentrations cover the entire range on both sides of 50%, the entire series is given under the first of the two type formulae; *e.g.*, all of the Ag-Al data are given under Ag-Al, and under Al-Ag there is merely a cross-reference. If on one side of the 50% concentration there are very few data, all of the data are given under the entry appropriate to the more numerous. There are certain obvious irregularities at the beginning of the Fe data.

Alloys with distinctive names are indexed in Table 1.

Room temperature (17 to 23°C) is to be assumed unless another is indicated. All temperatures are expressed in °C; concentrations in weight % unless another is indicated; resistivities in microhm-cm (=  $10^{-6}$  "ohm per cm cube") unless the experimenter used an assumed value for the resistivity of a standard metal, in which case this is indicated by the form "(For Ag,  $\rho_0$  = 1.54)." Units of the other quantities accord with the definitions of the corresponding symbols (*see* p. 157).



TABLE 2.—(Continued)

Ag-Al				
Al (38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
0	1.47	1.52	4.15	3.97
1.3	11.05	10.87	0.57	0.65
2.7	16.9	16.5	0.45	0.58
6.1	31.1	31.75	0.47	0.27
7.7	36.4	34.7	0.69	0.75
8.6	46.7	33.0	0.44	0.67
10.0	35.3	32.8	0.51	0.71
11.1	33.9	32.4	0.65	0.80
12.9	31.4	30.9	0.67	0.74
14.1	26.0	27.6	1.35	1.07
15.7	26.3	29.3	0.92	0.90
16.7	25.7	29.6	0.86	0.76
20.0	18.5	27.25	1.06	0.66
28.1	13.9	20.8	1.17	0.63
37.5	9.71	17.55	1.56	0.79
50.6	6.85	13.5	1.80	0.68
69.6	5.46	8.0	2.03	1.39
83.1	4.53	5.13	2.10	1.52
100.0	2.49	2.60	4.25	4.10

94% Al (63, 76)

$t$	$\rho_t$	$t$	$\rho_t$
-197.1	2.484	+0.9	4.654
-106.1	3.477	16.25	4.824
-81.9	3.723	92.5	5.686
0.0	4.641	$\alpha_{15} = 2.38$	

Ag-Au (19); cf. (182, 189)

Au	$\rho_0$	$\alpha$	Au	$\rho_0$	$\alpha$
3.51	2.29	2.66	76.83	9.925	0.79
14.45	4.295	1.47	85.85	8.0	1.02
32.29	7.645	0.90	94.14	4.925	2.89
52.27	10.09	0.72	98.84	2.76	3.90
66.01	10.21	0.72			

Annealed (182, 188, 189)

Au	$\rho_0$	$\alpha_0$	$\beta_0$
31.3	6.96	0.91	0.18
67.1	10.2	0.72	0.02
88.0	7.16	1.14	0.13

Drawn (wire)

Au	$\rho_0$	$\alpha_0$	$\beta_0$
31.3	6.97	0.89	0.25
67.1	10.24	0.67	0.21
88.0	7.24	1.09	0.39

90% Au (63, 76)

$t$	$\rho_t$	$t$	$\rho_t$
-197.1	4.817	+0.9	6.293
-106.1	5.510	16.4	6.417
-81.9	5.666	91.65	6.997
0	6.280	$\alpha_{15} = 1.25$	

66.67% Au (230); for Ag,  $\rho_0 = 1.54$ 

	$\rho_0$	$\alpha$		$\rho_0$	$\alpha$
Hard.....	10.24	0.65	Soft.....	10.21	0.87

Ag-Au-Cu; v. Au-Ag-Cu

Ag-Bi (182)

Bi	$\rho_t$	$t$	Bi	$\rho_t$	$t$
0.0	1.54	0.0	88.5	86.5	20.3
2.2	3.22	22.9	94.0	93.4	21.6
16.0	19.05	20.3	95.8	116.6	19.9
49.0	33.0	22.4	97.9	135.0	21.4
65.8	46.7	21.4	99.0	138.7	21.4
79.4	62.8	20.1	99.7	137.4	21.3

Ag-Cu

Cu (153)	$\rho_{25}$		$25\Delta_{100}$	
	A	O	A	O
0.0	1.620	1.684	4.17	3.97
0.2	1.700		3.99	
2.4	1.822	1.909	3.81	3.49
4.2		2.053		3.23
6.2	1.914	2.110	3.74	3.03
16.4	1.845	2.181	3.65	3.00
28.1	1.844	2.130	3.76	3.23
41.8	1.913	2.162	3.80	3.20
57.9	1.909	2.284	3.74	2.93
77.95	1.895		3.87	
91.80	1.832	2.271	3.89	3.21
95.02		2.169		3.15
96.65	1.875	2.030	3.85	
98.31		1.902		3.61
99.15		1.856		3.91
100.0	1.706	1.750	4.33	4.11

Dd, for Ag,  $\rho_0 = 1.54$  (182, 188, 189)

Cu	$\rho_t$	$t$	$\alpha$	$\beta$
0.00	1.54	0		
1.31	1.57†	9.8	3.37†	4.25†
1.31	1.63	9.8		
1.71	1.84	17.0		
2.76	1.97	17.1		
5.26*	2.07	16.8		
7.11	1.91†	9.0	2.75†	3.24†
7.11	1.97	9.0		
11.43	2.285	17.5		
15.6	2.42	17.0		
25.5	2.42	17.2		
35.15	2.37	19.6		
41.4	2.28	19.0		
42.7	2.02†	14.2	2.81†	2.59†
42.7	2.14	14.2		
59.5	2.26	22.2		
63.8	2.27	19.0		
74.7	2.19†	14.6	3.04†	3.16†
74.7	2.31	14.6		
75.5	2.27	18.8		
88.3	2.20	21.1		
94.0	2.04	20.0		
94.4	1.87†	16.0	3.25†	4.65†
94.4	1.97	16.0		
97.6	1.94	19.7		
98.1	1.71†	9.5	3.45†	3.93†
98.1	1.78	9.5		
98.7	1.772	20.7		

\* For 5.3% Cu,  $\Delta H = 8.6$  if  $t_A = 700^\circ\text{C}$  (112).

† From (188).



## Ag-Mg (254)

Mg	$\rho_{25}$	$\alpha_{25}^*$
0.00	1.637	
0.04	1.78	3.81
0.1	2.14	3.21
0.17	2.23	
0.24	2.52	
0.82	3.41	
1.55	4.65	
2.91	6.28	
6.75	6.85	1.93
7.55	6.86	
8.89	6.83	1.61
9.60	7.05	1.71
10.31	7.25	
11.31	7.28	
13.14	7.67	1.65
17.11	6.77	1.99
17.87	5.88	2.34
18.65	4.87	3.10
19.82	5.73	2.70
20.26	5.82	
21.6	6.27	2.31
23.03	7.82	
23.1	7.74	2.05
28.00	11.74	1.79
32.21	13.53	2.02
34.73	17.99	1.78
35.1	15.01	1.81
38.28	16.93	2.46
39.57	15.53	2.90
39.68	16.23	3.09
43.67	22.05	1.59
44.39	19.7	2.32
62.67	14.31	2.10
72.31	11.25	
79.34	9.91	
83.88	9.42	
89.29	8.54	
89.46	8.19	2.56
91.75	7.17	
93.45	7.27	
96.2	6.87	
98.08	5.96	
100.0	4.61	3.98

\* 25 to 100°C.

## Ag-Pb (182, 188, 189)

Pb	$\rho_t$	$t$
0.00	1.54*	* 0
0.96	2.294	23.4
14.5	3.225	23.8
32.4	9.85†	13.9
49.0	13.17‡	16.5
65.8	14.41	15.6
78.3	17.15	26.1
8.4	18.14	26.6
95.1	19.11§	24.3
97.9	19.47	25.3

\* Assumed as basis.

†  $\rho_0 = 7.04$ ;  $\alpha_0 = 2.0$ ;  $\beta_0 = 1.38$  (189).‡  $\rho_0 = 11.43$ ;  $\alpha_0 = 1.96$ ;  $\beta_0 = 0.75$  (189).§  $\rho_0 = 16.66$ ;  $\alpha_0 = 3.62$ ;  $\beta_0 = 5.16$  (189).

## Ag-Pd

Pd (81)	$\rho_0$	$\alpha_0^*$
0	1.57	4.1
10	6.05	0.91
20	10.43	0.47
30	15.4	0.36
40	21.75	0.36
50	32.8	0.26
60	42.0	0.03-0.07
70	38.77	0.25
80	30.68	0.66
90	20.6	1.17
100	10.56	3.28

\* 0 to 160°C.

Pd (173, 188, 189, 190)	$\alpha_0$	$\beta_0$
20	0.4336	0.2067
25	0.3576	0.1161
25*	0.3246	0.0488
25†	0.32	-0.05

\* From (190).

† From (188, 189);  $\rho_0 = 18.08$  if for Ag,  $\rho_0 = 1.54$ .

## 20% Pd (62)

$t$	$\rho_t$
-182	13.797
-100	14.256
-80	14.482
+ 0.8	14.965
20	14.984
99.8	15.409

## Ag-Pt (277)

Pt	$\rho$
0.0	2.17
10.39	9.18
20.59	18.14
31.46	29.14
37.89	31.10

## 33% Pt, 66% Ag (63); cf. (62)

$t^*$	$\rho_t$
-197.1	30.173
-166.1	30.790
-81.9	30.964
0.0†	31.582†
+ 1.85	31.573
16.1	31.726
93.25	33.296

 $\alpha_{15} = 0.243$ \* Pt scale of  $t$ .† Same values given (76) for PtAg<sub>1</sub> (= 31.1% Pt) (58).

## 32% Pt, 67% Ag (58)

$\rho_0$	$\alpha$
28	0.24

## 0° (273)

Pt	$C_t^*$	$\rho$	$\alpha$
28.95	0.55	29.0	0.261
32.95	0.40	29.9	0.262

\* For analysis, see (273).

## Ag-Pt.—(Cont'd)

Pt (273)	$\alpha$
25	0.377
25	0.407
30	0.313
33‡	0.301
33‡	0.265
40	0.259

## Dd (188, 189)

Pt	$\rho_0$	$\alpha$	$\beta$
5.0	4.87	1.24	+0.40
9.8	8.53	0.77	-0.06
33.3	23.0	0.33	-0.10
35*		0.3480	-0.2807

\* From (173).

## 67% Pt, 33% Ag

$\rho_0$	$\alpha_0$	Lit.
24.2	0.24-0.33	(144)

## Ag-Sb (119)

Sb	$\rho_{18}$	
27.34	107.5	SbAg <sub>3</sub>

## Ag-Sn (182, 189)

Sn	$\rho_t$	$t$
0.00	1.54	0.0
0.65	4.31	20.7
1.41	6.43	20.6
4	16.92*	54.00
51.8	10.73	20.6
68.3	12.23†	19.8
76.4	12.58	23.3
86.6	13.35	20.1
90.7	13.32	20.1
92.8	13.31	20.3
95.1	13.43‡	20.3
96.4	13.43	20.3
99.0	13.54	21.9

\* From (244);  $\alpha_0 = 0.724$  if  $54^\circ < t < 78^\circ$ .†  $\rho_0 = 10.8$ ;  $\alpha_0 = 3.77$ ,  $\beta_0 = 5.68$  (189).‡  $\rho_0 = 12.33$ ;  $\alpha_0 = 3.72$ ,  $\beta_0 = 6.39$  (189).

## Ag-Te; v. Te-Ag

## Ag-Tl (244)

Tl	$\rho_t$	$t$	$\alpha_0$
2.73	4.73	23.58	1.05*
4.76	7.57	49.33	1.25†

\* 23 to 38°C. † 49 to 89°C.

## Al, Commercial; v. Al-Fe-Si

## Al-Ag; v. Ag-Al

## Al-Bi; elect. Bi

Bi (38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
6.52	2.92	3.12	4.20	4.08
15.56	3.29	3.51	4.18	3.82
28.7	3.60	3.83	3.91	3.43
60.8	7.81	8.55	3.38	2.38
78.4	19.23	19.46	3.24	1.58
89.4	45.67	45.88	2.85	1.50
97.05	73.0	91.75	3.22	1.17
98.5	106.4	120.5	3.39	1.21
99.4	117.6	142.9	3.98	2.25
100.0	107.5	117.6	4.78	4.31
100.0	107.5*	164.0*	4.78	0.82

\* Commercial Bi.

## Al-Ca (30)

Ca	$\rho$	Ca	$\rho$	Ca	$\rho$
3.07	15.8	23.9	99.5	37.7	110.0
6.0	20.2	25.0	113.4	50.0	141.0
9.1	27.1	28.5	117.0	60.0	171.0
12.5	38.4	31.3	118.0	75.0	189.0
19.4	49.5	32.8	112.0	78.8	112.0

## Al-Cu; v. also Table 3

Cu (34, 38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
3.80	3.23	4.26	3.75	2.93
8.66	3.59	4.53	3.43	2.06
18.5	3.94	5.29	3.25	2.10
28.2	4.31	5.40	3.04	1.90



Al-Cu.—(Continued)

Cu (34, 38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
39.2	5.08	5.99	2.68	1.96
48.4	5.75	6.33	2.45	2.15
51.3	6.06	6.67	2.31	2.20
54.0	6.58	7.19	2.23	2.25
60.5	7.09	8.07	2.22	2.05
66.9	7.69	8.70	2.11	2.01
70.3	8.27	10.94	2.08	1.09
74.4	10.20	14.67	1.47	0.91
77.1	11.6	15.3	1.18	0.99
78.0	11.3	15.4	1.41	1.02
78.6	28.1	28.6	0.80	0.80
79.8	28.9	28.25	0.65	0.62
82.6	21.2	15.5	0.70	0.58
86.1	15.8	12.0	0.91	1.20
89.0	13.7	7.46	1.40	1.66
90.5	11.8	14.6	1.13	0.71
93.1	10.85	13.3	0.97	0.59
95.3	9.95	10.4	0.81	0.55
98.8	5.85	5.72	0.85	0.86
100.0	1.54	1.56	4.28	4.25

Aluminium bronze (212, 214); cf. Cu-Al-Ni 6% Cu (63, 76)

Cu	$\rho_0$	$\alpha_0$	$\beta_0$	$t$	$\rho_t$
6	3.10	3.8	3	-197.1	0.719
90	12.61	0.32	2	-106.1	1.715
92.5	13.62	0.36	1	-81.9	1.960
94	11.62	0.55	2	0.0	2.904
95	10.21	0.70	2	+ 0.95	2.911
97	8.26	1.02	3	16.35	3.087
				92.4	3.972
					$\alpha_{15} = 3.81$

Al-Cu-Fe-Si

15°C; ( $t_A = 435^\circ\text{C}$ ) (1/100%) (205, 295, 297)

Cu	Fe	Si	$\rho_A$	$\rho_0$	$\Delta_{100}^*$
2	15	16	2.75†		
11	37	31	2.83	2.92	3.18
16	25	38		2.88	3.24
158	25	38	3.30	3.34	2.83
186	31	40	3.18	3.25	3.03
261	40	40	3.26	3.34	2.96
9	116	35	2.96	2.97	3.57

\* Unannealed. †  $t = 20^\circ\text{C}$  (205).

Al-Cu-Mg-Fe-Si, Duralumin wire

$t_A = 400^\circ\text{C}$ , 0.41% Fe, 0.22% Si, 2.58% Cu, 1.26% Mg,  $\rho_A = 3.35$  (195)

Al-Cu-Ni-Fe-Si

$t = 12$  to  $14^\circ\text{C}$ ,  $t_A = 450^\circ\text{C}$ , Fe = 0.14 to 0.17%; Si = 0.12 to 0.17% (226)

Cu	Ni	$\rho_A$	Cu	Ni	$\rho_A$
0	1.87	2.96	2.00	1.12	3.28
0	4.31	3.19	3.05	1.00	3.42
0.99	0.90	3.22	4.07	1.12	3.32
1.03	3.04	3.34	4.13	2.16	3.55

Al-Fe

Fe (38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
0	2.44	2.60	4.25	4.10
12.8	6.49	6.76	3.51	2.96
24.3	13.3	14.2	3.19	2.26
33.6	43.3	44.8	2.56	1.53
40.5*	140.8	166.6	1.68	0.23
49.9		833		0.10

\*  $\text{Al}_3\text{Fe}$ .

Al-Fe-(Cu, Mn, Si); v. Al-Mn-Fe-Si-Cu

Al-Fe-Ni-Si-Cu; v. Al-Ni-Fe-Si-(Cu)

Al-Fe-Si (211, 214)

Impure Al;  $0^\circ\text{C}$ ; (1/100%); tr. of C

Fe	Si	$\rho_0$	$\alpha_0^*$
7	6	2.72	4.2
12	tr.	2.75	4.0
25	12	2.80	4.6

\*  $\rho_0 = 4$ ;  $0^\circ < t < 370^\circ$ .

Commercial Al,  $t_A = 450^\circ\text{C}$ , (1/100%) (110)

Casting		
Fe	Si	$\rho_A$
18	23	2.93
49	47	3.08

Al-Fe-Si.—(Cont'd)

Fe	Si	$\rho_A$
83	16	3.02
130	32	3.23

Wire and laminae

Fe	Si	$\rho_A$	$\Delta^*$
24	25	2.84	0.04
42	51	2.91	0.11
53	68	2.93	0.20
91	89	2.99	0.28

\*  $\Delta = \rho_0 - \rho_A$ .

(1/100%) (297)

Fe	Si	$\rho_{15}$	$\Delta_{100}$
31	14	2.76	3.93

Al-Fe-Si-Cu; v. Al-Cu-Fe-Si

Al-Mg

Mg (38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
3.76	6.02	6.45	2.10	1.92
6.92	6.99	7.09	1.80	1.80
14.46	10.41	10.42	1.17	1.34
18.06	12.20	12.36	0.94	1.09
21.79	14.71	14.97	0.65	0.91
29.73	26.60	28.40	0.69	0.49
31.23	27.79	31.15	0.45	0.50
35.86	40.66	37.18	0.33	0.34
40.0	49.26	45.46	0.34	0.25
47.75	38.03	37.31	0.47	0.28
52.28	45.06	43.48	0.29	0.26
53.89	38.48	36.36	0.41	0.34
54.95	32.57	31.46	1.44	0.80
57.69	22.07	23.09	4.10	3.75
60.29	30.77	29.86	0.90	1.03
64.74	24.52	27.40	1.02	0.75
73.02	19.92	22.84	1.03	0.84
85.26	16.47	17.30	1.32	1.10
92.85	14.22	14.01	1.45	1.28
100.0	40.64	42.54	4.30	4.15

Mg (64)	$\rho$	Mg (64)	$\rho$
85 C*	17.19	94	10.42
88 B*	16.34	96	9.40
90	15.36	98	7.48
92 A*	13.35	100	4.54

\* Duralumin A, B, C.



Al-Mg.—(Continued)  
Cast rod A<sub>308</sub> for 15 hr, in vacuum (192)

Mg	$\alpha_0$	Mg	$\alpha_0$
31.00	0.14.1	43.30	0.0846
34.43	0.1353	44.24	0.3690
34.48	0.1648	44.43	0.4243
35.92	0.2984	47.12	0.5755
39.54	0.2800	50.25	0.4202
Mg (205)	$\rho_{20}$	Mg (205)	$\rho_{20}$
10	8.28	90	19.18
12.5	7.61	100	47.5

Al-Mg-Ni (205), with 8% Mg and 2% Ni,  $\rho_{20} = 7.72$

Al-Mn

Mn (38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
6.3	14.27	14.6	0.26	0.24
12.6	20.1	20.7	0.34	0.41
21.4	35.7	34.6	0.42	0.70
32.8	84.0	96.6	0.66	0.82
40.4	500	294	1.10	1.22
46.9	2000	711	-0.63	0.42

Al-Mn-Fe-Si-Cu  
15°C; (1/100%) (295, 297)

Mn	Fe	Si	Cu	$\rho_0$	$\Delta_{100}$
5	54	32	2	3.09	3.11
35	35	31	3	3.30	2.91
178	56	44	9	3.49*	2.45

\*  $\rho_A = 3.35$ .

Al-Ni

Ni (38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
11.4	4.14	4.0	2.54	2.63
22.4	7.81	7.04	1.56	2.20
30.2	9.9	9.18	1.55	1.74
42.4	28.8	15.15	2.53	1.45
44.6	34.8	23.5	1.12	0.98
83.5	62.9	80.6	1.06	0.62
86.5	59.5	64.5	0.88	0.49
88.5	75.8	72.5	0.67	0.29
92.8	61.4	67.1	0.53	0.19
96.6	24.9	31.25	1.05	0.85
98.4	17.7	17.8	2.07	1.53
100.0	11.96	13.14	5.22	4.98

Al-Ni-Cu-Fe-Si; v. Al-Ni-Fe-Si-(Cu)

Al-Ni-Fe-Si-(Cu); v. also Al-Cu-Ni-Fe-Si  
15°C; (1/100%) (295, 297)

Ni	Fe	Si	Cu	$\rho_0$	$\Delta_{100}$
75	25	37	5	3.05	3.20
119	29	35	9	3.24	3.20
225	110	37	6	3.18*	3.29
129	43	37	108	3.41†	1.78
139	257	39	10	3.24‡	3.20

\*  $\rho_A = 3.14$ . †  $\rho_A = 3.28$ . ‡  $\rho_A = 3.20$ .

Al-Ni-Zn-Fe-Si-Cu  
15°C; (1/100%) (250, 295)

Ni	Zn	Fe	Si	Cu	$\rho_A$ *	$\Delta_{100}$ †
83	90	53	35	0	3	3.20
109	73	59	31	19	3.33	3.18
113	194	40	43	21	3.24	3.19
201	177	29	35	11	3.26	2.38
231	38	56	39	24	3.48†	3.00

\*  $\rho_0 - \rho_A = 0$  to 0.15. † Not annealed.

Al-Si-Fe-Cu; v. Al-Cu-Fe-Si

Al-Sn\*

Sn (38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
0.0	2.49	2.60	4.25	4.10
12.5	3.66	3.65	2.87	2.79
23.25	4.05	3.85	2.69	2.56
40.1	5.44	4.63	2.55	2.75
52.7	6.99	4.95	2.46	2.99
64.5	8.85	5.78	2.78	2.76
72.9	8.27	6.67	2.75	3.18
74.0	8.85	6.58	2.84	3.03
79.8	9.43	7.46	2.90	2.93
81.5	9.61	7.64	2.78	2.80
86.2	10.19	8.27	3.08	3.24
91.6	10.62	9.17	2.97	3.13
96.25	10.75	10.20	2.93	3.03
98.2	12.12	11.65	3.15	3.50
100.0	11.43	13.00	3.17	3.40

\* Impurities in Sn < 0.2%.

Al-Zn

Zn* (38)	$\rho_0$		$\Delta_{100}$	
	A	Tp	A	Tp
0.0	2.49	2.60	4.25	4.10
11.3	3.90	3.88	2.23	1.66
21.7	4.97	5.38	1.94	1.20
38.7	5.71	6.49	1.72	1.10
51.9	5.81	6.62	1.63	1.21
63.1	5.95	6.80	1.48	1.12
72.2	5.95	6.90	1.68	1.19
79.9	5.92	6.94	1.59	1.13
85.3	5.95	7.04	1.73	1.29
90.55	6.06	6.90	1.65	1.37
95.5	6.02	6.94	1.86	1.22
98.1	5.95	7.00	2.45	1.56
100.0	5.41	8.93	4.38	2.05

\* Al contains 0.1 Fe + 0.2 Si.

Zn (307)	$\rho_{18}$	$\rho_{350}$	Zn (307)	$\rho_{18}$	$\rho_{350}$
0.00	2.77		41.08	5.06	10.51
4.89	3.34		48.95	5.14	11.06
8.02	3.67		57.17	5.56	13.52
10.00	4.01		63.77	5.47	13.52
11.98	4.43		70.30	5.56	14.01
15.08	4.63		75.30	5.38	14.01
17.80	4.88		77.95	5.53	14.01
19.44	5.05	9.89	80.00	5.5	13.52
25.00	5.04	9.49	82.30	5.65	14.01
30.82	4.88	9.52	86.10	5.7	14.01
35.20	5.09	10.31	96.05	5.88	15.58

Al-Zn-Cu-Si-Fe; v. Al-Zn-Si-Fe-Cu

Al-Zn-Ni-Fe-Si-Cu; v. Al-Ni-Zn-Fe-Si-Cu



Al-Zn-Si-Fe-Cu  
15°C; (1/100%) (295, 297)

Zn	Si	Fe	Cu	$\rho_0$	$\Delta_{100}$
62	38	22	17	2.86	3.57
120	43	28	30	2.94	3.20
204	43	39	9	3.07	3.25
59	37	28	59	3.06	3.06
120	39	31	63	3.12	3.16

Au-Ag; v. Ag-Au

Au-Ag-Cu, 20°C (75)

Ag	Cu	$\rho_A$	$\Delta_H$	$\alpha^*$
4.72	95.28	2.375†		3.12†
6.27	59.25	8.80	3.4	0.763
9.64	5.83	10.84	1.5	0.764
15.64	1.89	9.81	1.2	0.851
3.96	21.60	13.96	0.2	0.516
11.52	16.29	13.65	0.7	0.550
25.34	6.58	12.50	1.4	0.644
32.29	2.11	11.40	2.6	0.693
4.53	29.25	13.60	2.2	0.553
23.34	18.15	12.61	4.8	0.620
36.52	2.46	11.21	0.1	0.653
0.00	49.16	11.37	3.5	0.632
5.43	44.85	11.40	2.8	0.624
15.61	36.8	11.06	5.8	0.631
29.3	26.0	10.46	5.4	0.678
52.3	7.74	9.61	4.5	0.749
58.95	2.48	9.02	3.2	0.779

\* Annealed;  $W_k$  decreases  $\alpha$  by 1 % to 6 %. † Cold worked.

Ag (196)	Cu	$\alpha_0$	$\beta_0$
14.3	78.3	1.833	+0.5746
15.2	26.5	0.5742	-0.5946
18.06	15.44	0.5295	+0.1869

18 Karat Gold (201); Au, 75; Ag, 10-20; Cu, 5-10;  $\rho_0 = 8.53$ ;  $\Delta_{100} = 1.08$

Au-Bi; v. Bi-Au

Au-Cd (240)

Cd	$\rho_{25}$		$\alpha_{25}^*$	
	O	Tp	O	Tp
0	2.34	2.296	4.27	4.45
5.05	4.12	4.04	2.41	2.62
14.44	6.675	6.81	2.58	2.44
30.36	13.14	12.36	1.50	1.35
35.44	16.6	15.4	1.19	1.31
40.77	11.31	10.08	1.72	2.16
43.23	10.55	10.03	1.88	2.34
44.05	9.745	10.23	1.92	2.34
46.34	8.365	9.2	2.43	2.67
48.4	7.725	7.71	6.07	6.24
49.76	7.5	7.39	6.55	6.36
50.27	7.32	7.47	5.44	5.67
51.36	8.825	8.72	2.35	3.06
55.89	16.5	14.31	1.74	1.89
60.32	17.6	17.7	1.93	1.93
70.21	14.6	14.73	2.18	2.46
72.93	14.09	14.51	2.05	2.73
74.07	14.0	13.9	3.15	3.50
74.89	13.3	13.27	4.05	4.17
75.87	13.495	15.03	2.56	2.71
78.56	12.5	33.4	2.01	1.64

Au-Cd.—(Continued)

Cd	$\rho_{25}$		$\alpha_{25}^*$	
	O	Tp	O	Tp
81.89	12.01	28.15	2.77	2.35
84.93	11.42	26.45	2.55	2.35
88.01	10.27	18.65	2.94	2.97
89.87	9.375	16.34	3.02	2.60
91.03	9.645	15.17	3.38	2.50
92.17	9.55	14.3	3.13	2.20
92.95	9.57	12.92	2.76	2.84
94.05	9.29	10.9	3.17	3.11
94.95	9.5	9.49	3.31	3.31
98.1	9.36	9.295	3.38	3.39
99.05	9.16	8.95	3.74	3.64
100	7.4	7.26	4.42	4.32

\* 25 to 100°C.

Cd	$\rho_{100}$	$\alpha_{100}^*$	Cd	$\rho_{100}$	$\alpha_{100}^*$
0	3.56	5.77	51.36	11.63	3.98
5.05	5.12	2.47	55.89	16.54	
30.36	15.22	1.02	60.32	20.67	
40.77	14.23	3.07	100.0	11.55	
48.4	12.14	3.45			

\* 100 to 600°C.

Au-Cu

Cu (154)	$\rho_{25}$		$\alpha_0^*$	
	A	Tp	Tp	A
0	1.7	1.700	4.94	4.94
5	4.797	4.931	1.43	1.44
10	4.246	7.404	0.94	0.93
15	9.117	9.117	0.80	0.77
20	10.803	11.69	0.61	0.78
22.5		12.632	0.55	
25	5.729	12.396	0.59	0.97
27		13.686	0.52	
31.09	9.988	13.592	0.57	1.08
35	4.814	15.803	0.45	0.55
40	11.427	16.026	0.48	0.83
45	9.782	16.551	0.51	1.10
47		16.107	0.43	
49.16		16.292	0.49	
50	5.636	15.142	0.53	1.98
55	10.611	17.045	0.42	0.98
60	11.342	15.870	0.49	0.95
65	14.968	15.727	0.53	0.50
70	15.04	14.171	0.73	0.60
74.37		12.728	0.78	
75	13.233	12.792	0.76	0.66
85	11.095	11.136	0.89	0.76
90	7.738	7.916	0.96	1.14
95	6.858			1.36
100	3.144	3.144	2.93	2.93

\* If  $25^\circ \leq t \leq 100^\circ$ .

Cu	$\rho_{25}$	Cu	$\rho_{25}$
0	1.700 to 2.062	65	14.814 to 15.445
15	10.804 to 11.388	75	5.533 to 9.005
30	14.727 to 15.040		

For Ag,  $\rho_0 = 1.54$  (182, 188, 189); cf. (186)

Cu	$\rho_t$	$t$	Cu	$\rho_t$	$t$
1.1	3.30	19.1	14.5	12.16	19.6
2.0	4.67	19.4	28.9	13.45	17.8
4.1	6.86	17.9	43.0	12.32	20.1
8.2	10.03	20.3	50.7	11.0	17.1



## Au-Cu.—(Continued)

Cu	$\rho_t$	$t$	Cu	$\rho_t$	$t$
65.8	7.76	16.9	92.68	2.90	18.0
78.2	5.36	19.5	96.52	2.36	18.1
82.3	4.64	17.0			

Cu (182)	$\rho_0$	$\alpha_0$	$\beta_0$	Cu (189)	$\rho_0$	$\alpha_0$	$\beta_0$
0.7	2.74	2.65	2.38	66.2	7.51	0.86	0.18
9.5	9.61	0.75	0.48	98.48	1.83	3.32	3.72

## Au-Cu-Ag; v. Au-Ag-Cu

Au-Fe; v. also Fe-Au  
Wire, Dd (188, 189)

Fe	$\rho_0$	$\alpha_0$	$\beta_0$	Fe	$\rho_0$	$\alpha_0$	$\beta_0$
4.74	64.9	0.49	+0.13	9.825	74.7	2.98	-3.35
5.0		0.3720*	-0.3822*	13.55	56.1	3.5	+5.22

\* From (173).

## Au-Pd (80)

Pd	$\rho_0$	$\alpha_0^*$	Pd	$\rho_0$	$\alpha_0^*$
0	2.104	3.26	60	25.26	0.79
10	7.37	0.97	70	20.58	1.31
20	12.60	0.64	80	18.02	1.74
30	18.09	0.55	90	14.26	2.24
40	24.70	0.34	100	10.56	3.28
50	26.32	0.65			

\* 0 to 160°C.

## Au-Pt (81)

Pt	$\rho_0$	$\alpha_0^*$	Pt	$\rho_0$	$\alpha_0^*$
0	2.1	3.26	30	19.3	0.59
10	10.23	0.98	40	32.7	0.37
20	17.95	0.54			

\* 0 to 460°C.

## Au-Sn (182, 189)

For Ag,  $\rho_0 = 1.54$ 

Sn	$\rho_t$	$t$
0.41	7.86	18.8
0.81	11.73	21.4
12.82	29.75	15.0
22.75	17.35	15.9
37.05	10.79	18.1
41.9	17.4	21.0
54.05	30.1	22.3
59.5	36.0*	21.3
63.9	30.9	21.7
70.2	25.1	19.2
78.0	19.85†	19.8
85.2	16.8	24.2
88.6	15.45	23.8
96.75	13.86	23.6

\*  $\rho_0 = 30.45$ ,  $\alpha_0 = 2.92$ ,  $\beta_0 = 2.23$  (182).†  $\rho_0 = 18.63$ ,  $\alpha_0 = 3.09$ ,  $\beta_0 = 2.88$  (189).

Sn	$\rho$	(96)
37.6	11.1	AuSn
54.6	33.3	AuSn <sub>2</sub>
64.4	25	AuSn <sub>4</sub>

## Bi-Ag, Bi-Al; v. Ag-Bi, Al-Bi

## Bi-Au (182, 188)

For Ag,  $\rho_0 = 1.54$ 

Au	$\rho_t$	$t$
1.1	152.5	24.0
2.3	154.3	21.6
4.5	141.3	19.9
10.6	123.2	21.9
19.23	108.4	22.6
32.2	84.6	13.7
48.65	52.2	14.3

## Bi-Cd-Pb-Sn; v. Table 3

## Bi-Hg (284); (cf. Hg-Bi)

Hg	$R$	$t$
0.00	1.355	265.0
12.40	1.383	265.7
19.22	1.407	265.2
42.73	1.367	264.0
42.66	1.363	263.5
53.79	1.325	265.8
58.72	1.316	264.0
62.66	1.283	264.6
67.70	1.240	264.0
77.05	1.185	265.2
83.38	1.151	263.6
85.32	1.157	265.0
90.02	1.133	263.9
93.07	1.147	264.9
94.31	1.149	262.8
96.6	1.192	264.7
100.0	1.309	266.0

## Bi-Mg (265)

Mg	$\rho_{25}$	$\Delta_{100}$
1.6	141.6	4.19
2.5	142.6	4.17
4.45	149.3	4.23
6.7	154	4.39
12.5	131.2	3.85
16.5	49.0	3.65
22.1	31.1	3.74
35.4	12.5	4.10

Bi-Pb; v. also Pb-Bi in Table 3  
(182, 188, 189)For Ag,  $\rho_0 = 1.54$ 

Pb	$\rho_t$	$t$
0.3	170.4	25.8
0.4	252.5	23.8
0.50	359.7	24.8
0.55	496.8	25.6
0.7	529.1	25.0
1.0	570.4	21.3
1.6	590.0	22.9
2.0	599.1	24.1
2.4	568.2	24.0
3.4	532.9	23.9
4.0	508.2	23.9
4.7	492.1	21.3
5.8	431.4	22.6
7.6	380.3	21.5
11.1	295.6	20.0
19.9	179.2	19.9
33.3	109.2	19.2
49.9	73.7	22.2
66.9	53.6	22.5
75.0	44.4	21.3
79.95	38.3	21.7
83.3	35.4*	20.9
92.28	27.74	24.4*
97.96	21.9†	24.0

\*  $\alpha_0 = 2.307$ ,  $\beta_0 = 2.0$ .†  $\alpha_0 = 3.458$ ,  $\beta_0 = 5.06$ .0°C;  $t_A = 123$  (121)

Pb	$\rho_0$	$\rho_A$
0.00	131.2	134.5
2	284.8	295.8
4	290.2	271.6
6	275.9	273.1

## Bi-Sn (182)

For Ag,  $\rho_0 = 1.54$ 

Sn	$\rho_t$	$t$	Sn	$\rho_t$	$t$
0.1	142.6	25.2	12.1	148.1	29.9
0.3	386.4	27.1	21.8	68.8	28.5
0.5	583.1	26.3	35.7	38.9	25.7
0.6	628.4	26.8	52.3	26.4	23.8
0.95	604.0	24.1	62.55	21.9	27.9
2.7	432.8	24.7	69.0	19.7	24.9
4.4	300.0	29.7	92.37	14.8	24.2
6.5	243.6	29.6			

## Bi-Pb.—(Cont'd)

Pb	$\rho_0$	$\rho_A$
8	266.9	268.4
10	255.4	265.3
20	188.5	179.7
30	137.4	129.7
50	86.06	77.30
60	70.53	65.17
70	53.06	55.96
80	41.41	43.82
82	39.34	40.07
84	40.41	41.73
84.5	39.26	39.59
86	35.34	36.97
87.5	34.09	33.53
88	31.98	32.95
90	29.08	32.21
100.00	20.91	21.39

Pb (242)	$\rho$	Pb (242)	$\rho$
0	120.5	1.81	13.7
0.50	130.6	3.11	225.3
0.81	129.7	4.08	194.6
1.77	163.5		

## Bi-Pb-Sn; v. Table 3

## Bi-Pb-Sn-Cd

Lipowitz alloy (169); v. also  
Table 3; ca. Bi, 50; Pb, 25; Sn,  
14; Cd, 11; H-scale of  $t$ .

$t$	$\rho$	$t$	$\rho$
+ 19.6	47.5	-122.9	28.9
-176.6	21.3	- 92.1	33.2
-178.1	21.1	- 89.1	33.7
-178.5	21.0	- 87.0	34.0
-178.5	20.9	- 85.1	34.3
-175.7	21.0	- 37.4	40.4
-173.4	21.5	- 35.7	40.9
-170.5	21.8	- 35.0	41.0
-141.5	26.1	- 34.6	41.0
-134.6	27.4	+ 12.1	46.7
-129.3	27.9	+ 12.1	46.8
-125.4	28.3		

## Bi-Sb (180)

For Ag,  $\rho_0 = 1.54$ ; 3.03% Sb,  
 $\rho_{24} = 174.2$



## Bi-Sn.—(Continued)

Sn (285) = 19.67		31.08		39.65	
<i>t</i>	<i>R<sub>t</sub></i>	<i>t</i>	<i>R<sub>t</sub></i>	<i>t</i>	<i>R<sub>t</sub></i>
0	132.8	0	85.0	0	68.7
$\alpha_0 = 2.73$		$\alpha_0 = 3.07$		$\alpha_0 = 2.59$	
$D = 36.2$		$D = 26.1$		$D = 17.8$	
133.0	181.0	132.1	119.5	69.1	81.0
137.3	184.2	139.9	120.9	97.0	88.0
141.6	180.9	143.1	119.4	107.5	90.6
146.3	177.5	149.4	115.2	120.5	92.7
156.0	170.9	156.2	109.7	128.1	93.6
166.3	159.8	161.4	102.1	136.2	94.3
173.2	149.9	165.3	98.5	138.6	94.5
187.4	136.0	185.2	98.9	142.1	93.1
196.4	123.1	204.4	99.2	143.6	91.6
202.1	108.5	$D = 3.9$		147.3	90.8
214.7	111.1	253.8	101.1	155.5	88.3
$D = 3.3$		30.6	92.0*	$D = 4.3$	
260.0	112.6	65.9	99.6	252.8	92.5
34.6	1.443*				
60.0	1.519*				
90.4	1.646				

Sn (285) = 45.5		50.05		61.09	
<i>t</i>	<i>R<sub>t</sub></i>	<i>t</i>	<i>R<sub>t</sub></i>	<i>t</i>	<i>R<sub>t</sub></i>
0	54.4	0	47.7	0	30.4
$\alpha_0 = 3.07$		$\alpha_0 = 3.3$		$\alpha_0 = 4.64$	
$D = 16.7$		$D = 15.8$		$D = 14.0$	
137.9	77.4	129.5	68.1	137.7	49.7
139.8	77.9	135.6	70.8	141.6	50.9
145.3	82.0	141.6	74.4	147.1	53.0
149.4	82.4	148.6	78.7	156.2	57.1
$D = 4.5$		153.2	79.3	164.3	63.2
251.8	87.0	$D = 4.5$		172.4	70.5
45.6	61.3*	244.6	83.4	178.2	71.3
73.9	65.4*	58.7	56.3*	$D = 3.51$	
81.6	66.9*	81.9	59.9*	252.3	73.9
93.7	69.0*			35.9	34.6*
100.9	70.8*			50.2	36.0*
				59.4	37.0*
				74.4	39.1*
				91.0	42.2*

Sn (285) = 75.30		87.46		90.53	
<i>t</i>	<i>R<sub>t</sub></i>	<i>t</i>	<i>R<sub>t</sub></i>	<i>t</i>	<i>R<sub>t</sub></i>
0	26.0	0	18.3	0	16.2
$\alpha_0 = 3.22$		$\alpha_0 = 3.93$		$\alpha_0 = 3.70$	
$D = 8.39$		$D = 7.19$		$D = 5.98$	
133.6	37.2	176.7	31.0	158.7	25.7
135.4	37.2	184.7	32.6	167.0	25.8
137.9	36.5	199.0	38.3	186.2	28.4
141.8	37.0	206.9	47.8	198.2	31.0
144.6	37.4	210.0	54.6	211.5	40.0
151.2	38.4	212.1	57.2	217.4	52.9
157.7	39.6	217.1	57.2	224.7	55.3
179.2	46.9	$D = 3.9$		239.3	55.4
194.2	60.4	253.0	58.6	251.4	56.0
194.7	62.6	230.7	57.4*		
200.3	63.8				
$D = 2.57$					
254.8	65.2				
59.5	30.7*				
75.1	31.9*				

\* Falls below the line defined by *D* and its preceding *R<sub>t</sub>*.

## Bi-Sn.—(Continued)

Sn (242).....	0	0.34	0.71	2.15	7.43
$\rho$ .....	120.5	168.1	197.7	223.3	204.9

Duplicate specimens differ by 2% to 12%; following data are averages for two specimens of each composition (55):

Sn.....	0	1	2	3.71	6.36
$\rho_{20}$ .....	111.4	320.8	320.0	307.5	227.7
$\rho_{25}$ .....	117.3	326.7	327.6	316.6	235.2
$\rho_{50}$ .....	123.6	332.2	335.3	323.6	242.0
$\rho_{65}$ .....	130.0	336.2	340.0	330.0	250.0
$\rho_{80}$ .....	136.8	337.8	344.8	336.0	258.0
$\rho_{100}$ .....	144.8	340.5	349.1	340.2	267.2

Sn 7.69%,  $\rho_{22} = 296.6$ ; for Ag,  $\rho_0 = 1.54$  (180)Bi-Te (119); Te, 47.8%,  $\rho_{18} = 2000$ ; Bi<sub>2</sub>Te<sub>3</sub>

## Bi-Tl (104)

Tl	$\rho$	$\alpha_0$	$\beta_0$
0	110	3.32	5.45
1	128	2.62	5.075
10	110	1.68	9.54
20	90	1.89	7.80
30	69	2.41	4.71
37	45	2.90	2.22
40	84.6	1.27	0.591
53	96.8	0.740	0.511
60	105.1	0.418	0.951
80	68.8	0.7125	1.450
85	53.2	0.936	8.32
88.75	42.5	1.177	5.89
90	37.5	1.387	8.01
93	29.5	2.03	18.86
95	24.3	2.76	16.47
97.5	21.4*	3.15	2.10
	21.5†	2.81	5.35
98.5	19.2*	3.28	1.562
	10.4†	3.25	2.58
99.25	17.4	3.79	1.72
100	14.0	4.28	2.14

\*  $\alpha$ TL. †  $\beta$ TL.

## Ca-Al; v. Al-Ca

## Cd-Au; v. Au-Cd

CdCl<sub>2</sub>-Cd; v. Table 3

## Cd-Cu (24)

Cu	$\rho_{800}$	$\rho_{700}$	Cu	$\rho_{800}$	$\rho_{700}$
0.0	34.82	35.78	31.5	44.45	42.43
19.0	42.42	41.57	37.0	42.97	41.77
23.8	43.97	42.31	42.0	41.65	40.71
27.4	43.89	42.07			

## Cd-Mg (279)

Mg	$\rho_{25}$	$\rho_{50}$	$\rho_{75}$	$\rho_{100}$
0.0	7.46	8.077	8.78	9.61
1.1	9.43	10.215	11.15	12.05
2.4	11.45	12.18	13.02	13.90
3.7	14.08	14.83	15.625	16.34
4.15	14.94	15.798	16.667	17.64
5.2	12.00	14.493	17.36	18.73
6.75	16.64	17.482	18.18	18.87
8.5	27.32	29.59	30.52	36.36
9.4	29.41			37.03
10.35	28.33	30.303	33.00	36.36
11.5	20.49			25.0



## Cd-Mg—(Continued)

Mg	$\rho_{25}$	$\rho_{50}$	$\rho_{75}$	$\rho_{100}$
12.6	18.08	18.832	19.88	20.84
15.0	11.97	12.658	13.47	14.24
16.35	9.48	10.183	10.917	11.89
17.8	7.692	8.446	9.225	10.13
19.25	9.22	9.891	10.73	11.56
20.9	10.87	11.494	12.20	13.00
24.5	13.56	14.347	15.083	15.97
28.6	13.87	15.00	16.34	17.67
33.5	12.00	13.28	14.184	15.34
36.3	10.101	10.858	11.82	13.02
39.4	8.85	9.871	11.364	13.16
42.6	8.62	9.578	10.964	12.82
46.4	14.70	15.00	15.29	15.63
55.1	13.44	13.774	14.184	14.49
66.0	10.101	10.493	10.99	10.33
80.4	7.194	7.507	7.855	8.21
100.0	4.608	4.985	5.414	5.959

Mg	$\rho_{150}$	$\rho_{200}$	$\rho_{255}$	$\rho_{300}$
0.0	11.9	14.2	16.2	17.0
3.7	17.9	19.9	21.8	23.5
5.2	21.7	23.3	25.0	27.0
8.5*	44.25	45.45	46.1	46.95
12.6	25.0	31.25	35.0	35.7
15.0	16.4	18.7	25.6	26.8
17.8†	11.8	14.0	23.3	24.0
20.9†	14.9	17.0	25	25.8
24.5	18.1	21.4	27.1	27.7
28.6	20.8	25.0	25.6	26.3
36.3	16.67	20.84	21.45	22.26
42.6	17.24	18.8	19.3	19.95
46.4	16.39	17.51	18.18	18.9
55.1	15.23	15.92	16.42	16.92
100.0	7.64	9.8	11.86	13.27

\*  $\rho_{150} = 42.55$ ;  $\rho_{175} = 44.8$ .†  $\rho_{150} = 12.4$ ;  $\rho_{155} = 13.3$ ;  $\rho_{210} = 14.7$ ;  $\rho_{235} = 15.65$ ;  $\rho_{245} = 17.2$ ;  $\rho_{260} = 18.2$ ;  $\rho_{275} = 23.75$ .‡  $\rho_{155} = 15.4$ ;  $\rho_{160} = 16.4$ ;  $\rho_{222} = 20.0$ ;  $\rho_{242} = 24.9$ .

## Cd-Pb; v. also Table 3

Pb (19)	$\rho_0$	$\Delta_{100}$	Pb*	$\rho_t$	$t$
13.03	7.46	4.17	23.6	8.12	21.4
30.76	8.51	4.19	31.6	8.70	20.7
40.92	9.44	4.01	48.1	10.52	21.2
57.71	10.9	4.13	64.9	12.22	21.8
69.35	13.2	3.95	78.8	15.10	18.5
80.84	15.32	4.26	88.1	17.13	23.0
91.57	17.63	4.12	92.6	18.37†	21.9

\* For Ag,  $\rho_0 = 1.54$  (182, 188, 189).†  $\rho_0 = 16.58$ ;  $\alpha_0 = 3.50$ ;  $\beta_0 = 5.0$  (189).

## Cd-Sb (72)

Sb	$\rho_0$	$\rho_{-79}$	$\rho_{-190}$
33.3	372	292	156.8
50.0	1 699	1 257	730
51.7*	50 200	31 800	15 970
66.7	4 050	3 675	4 940

\* Cdsb.

## Cd-Sn (182, 188, 189)

For Ag,  $\rho_0 = 1.54$ 

Sn	$\rho_t$	$t$
14.7	7.54	20.5
20.6	7.85*	20.3
34.2	8.39	19.6
50.9	9.54	20.9
66.6	10.66	20.2
80.6	11.63†	22.3
86.1	12.10	22.1

\*  $\rho_0 = 6.96$ ;  $\alpha_0 = 3.85$ ;  $\beta_0 = 5.42$  (189). †  $\rho_0 = 10.62$ ;  $\alpha_0 = 4.07$ ;  $\beta_0 = 4.73$  (189). ‡  $\alpha_0 = 3.785$ ;  $\beta_0 = 6.33$ .

Co, commercial; v. Co-Fe

Co-Cu (227);  $A_{160}$ ; w = wire, r = rod

Cu	$\rho_{20}$	$\alpha$
0.2w	9.73	3.26
9.6r	24.30	1.67
19.5r	16.59	1.66
29.7r	14.79	1.50
40.6r	12.92	1.43
53.4r	11.34	1.32
65.6w	12.10	0.936
76.4w	11.43	0.817
86.8w	10.72	0.776
93.3w	10.02	0.801
96.9w	8.63	0.820
95.9w	9.45	0.771
96.9w	9.45	0.768
98.1w	8.80	0.859
98.5w	6.76	1.084
100.0w	1.672	4.45

Co-Fe (142); v. also Fe-Co-x  
"Pure cobalt"; 15.5°C; 0.017S;  
 $t_A = 800^*$ 

Fe	$\rho_0$	$\rho_A$
0.20	870	
22.5°C; 0.012S, 0.084Si, 0.0066P		
0.19	898	915
"Commercial cobalt"		
21.3°C; 0.023S, 0.09C, tr. Si, tr. Ca		
0.60	2308	
19.6°C; 0.012S, 0.039C, 0.14Si, 0.010P		
1.15	1049	904

\* For variation of  $\rho$  with  $t_A$ , v. (142).

Co-Fe-Ni (142); 21.95°C; 0.018S

Fe	Ni	$\rho_0$
4.49	2.73	1444

## Co-Ni (237)

Ni	$\rho_{17 \text{ to } 18}$	Ni	$\rho_{17 \text{ to } 18}$
0	6.41	60	10.11
5	6.80	70	11.16
10	7.15	80	11.86
20	7.54	85	11.90
30	8.37	90	11.33
40	9.24	95	10.46
50	9.72	100	7.72

## Cd-Zn (182, 188, 189)

For Ag,  $\rho_0 = 1.54$ 

Zn	$\rho_t$	$t$
8.9	6.85	19.4
12.7	6.74	20.3
22.3	6.57†	21.3
36.8	6.45	22.3
53.5	6.39	22.2
70.3	6.12	20.3
77.75	5.96	20.0

Cu-x (1);  $0 < x < 1\%$ 

x	k	x	k
Ag	6	P*	3000
Al*	500	Pb	3
As*	720	S	8
Au	10	Sb*	190
Bi	4	Si*	70
Cd	9	Sn	67
Fe	140	Te	4
O	25	Zn	30

\* For these elements the conductivity concentration curve is markedly curved from the outset, and the values of k have been obtained from a tangent to the curve at zero concentration. These values can therefore only be used for concentrations of a small fraction of 1%.

## Cu-Ag; cf. Ag-Cu

For Ag, $\rho_0 = 1.54$		1.70% Ag	
Dd wire (186)		(24)	
Ag	$\rho_0$	$t$	$\rho_t$
1.21	1.77	1100	21.45
$D = 0.343$			
2.39	1.94	1400	22.48

## Cu-Ag-Au; v. Au-Ag-Cu

Cu-Al; 3% Al ( <sup>63</sup> ); cf. Al-Cu			
<i>t</i> <sup>*</sup>	$\rho_t$	<i>t</i> <sup>*</sup>	$\rho_t$
-197.1	7.328	+0.85	8.660
-106.1	8.044	16.35	8.990
- 81.9	8.210	92.25	9.575
0.0	8.847	$\alpha_{15} = 0.897$	

\* Pt scale of  $t$ .

## Cu-Al-Ni; cf. Al-Cu-Ni-Fe-Si

Al (225)	Ni	$\rho_A^*$
5.21	7.31	18.45†
5.32	4.84	15.47†
4.94	2.38	12.56
5.10	0.94	10.88
5.02	0.0	9.85
9.88	2.46	14.40
9.82	1.04	11.74
10.06	0.0	10.27

\*  $t_A = \text{"red" heat}$ .†  $\rho$  is same for  $t_A = 900^\circ\text{C}$ .Aluminium bronze; cf. Al-Cu  
6.5% Al, 6.5% Ni (63, 76, 212)

$t^*$	$\rho_t$	$t^*$	$\rho_t$
-197.1	13.048	+0.9	14.921
-106.1	13.939	16.35	15.066
-81.9	14.132	91.45	15.785
0.0	14.912	$\alpha_{15} = 0.645$	

\* Pt scale of  $t$ .



## Cu-Al-P (224)

Al	P	$\rho_{11.6}$
4.88	0.20	11.67
4.94	0.09	11.02
4.97	0.06	10.36
5.02	0.0	9.85
9.96	0.11	10.75
10.05	0.05	10.53
10.06	0.0	10.27

## Cu-As (221)

As	$\rho_0$	$\Delta_{100}$
0.25	3.04	2.31
0.5	3.79	2.02
0.75	5.22	1.49
1.0	6.31	1.26
1.5	8.58	0.943
3.0	17.3	0.475
4.0	22.5	0.376
5.0	26.2	0.275
6.0	34.8	0.261
10.0	38.5	0.449
15.0	47.4	0.940
20.0	54.3	1.59
25.0	56.5	2.39
28.5	59.0	2.74
31.2	58.2	2.66
32.3	50.3	2.68
33.1	56.6	2.65
34.9	57.1	2.69
36.5	54.8	2.74
37.8	53.2	2.71
39.4	50.7	2.99
42.0	49.3	2.70

For Cu,  $\rho_{18} = 1.78$ 

As	$\rho_{18}$
Rod (228)	
1.04	4.92
1.80	7.18
2.66	9.84
2.8	12.6
3.0	11.35
5.02	27.0
5.4	26.85
Sheet (228)	
1.99	4.68
4.83	17.8

For Ag,  $\rho_0 = 1.54$ ; Dd wire (186, 188, 189)

As	$\rho_0$	$\alpha_0$	$\beta_0$
tr.	2.52	2.64	6.52
2.80	12.51	0.74	0.10
5.40	24.1	0.37	0.04

## Cu-As-O (87)

As	O	$\rho_t$	$t$
0.05	0.26	2.169	17
0.06	0.3	2.485	18
0.22	0.16	3.178	18
0.4	0.17	3.843	18
0.43	0.42	4.251	17
0.49	0.1	4.690	18

## Cu-Au; v. Au-Cu

## Cu-Au-Ag; v. Au-Ag-Cu

## Cu-Cd; v. Cd-Cu

## Cu-Co; v. Co-Cu

## Cu-Cr; cf. Cu-Ni-Cr

Cr (135)	$\rho_A$	$\rho_{Dd}$
0	1.697	1.738
0.498	1.788	3.635
0.99	1.832	3.160
4.76	1.986	3.701
6.51	2.404	3.902
9.1	2.209	3.940
13.04	2.324	4.268
14.74	2.52	4.296

Cr (249)	$\rho_t$	$t$	$\alpha_{20}$
4.2	2.084	18.55	3.76
9	2.209	18.7	3.74
13	2.723	22.1	3.44
16.7	3.372	18.75	2.44

## Cu-Fe; cf. Fe-Cu

A<sub>1000</sub> in N (236)

Fe	$\rho$	Fe	$\rho$
0	1.93	50	6.37
0.5	3.16	60	7.28
0.8	3.36	70	8.63
1	3.36	80	10.10
1.5	3.51	90	11.36
2	3.60	92	11.84
4	3.66	94	12.27
6	3.75	96	13.01
8	3.87	97	14.00
10	3.99	98.5	14.00
15	4.08	99	16.04
20	4.47	99.5	13.70
30	4.99	100	11.84
40	5.77		

## Dd wire (186)

Fe	$\rho_0$	Fe	$\rho_0$
0.48	4.46	1.05	5.72

## Dd, 0.4Fe, (188, 189)

$\rho_0$	$\alpha_0$	$\beta_0$
3.86	1.55	0.33

## Cu-Mg (265)

Mg	$\rho_{25}$	$\Delta_{100}$
0.56	2.115	3.54
0.65	3.25	2.27
0.77	3.339	2.10
1.53	4.185	1.83
2.97	4.784	1.21
3.28	5.061	1.22
6.75	6.214	1.57
8.76	5.641	2.26
10.06	5.952	2.25
11.65	5.411	2.50
14.53	5.803	2.57
15.38	5.746	2.51
15.47	5.717	2.50
16.05	5.538	2.90
16.28	5.16	3.14

## Cu-Mg.—(Cont'd)

Mg	$\rho_{25}$	$\Delta_{100}$
16.46	5.145	3.16
17.71	5.509	3.07
22.66	6.069	2.75
23.7	6.371	3.28
26.7	6.146	2.91
27.55	6.83	2.81
31.9	7.134	3.16
34.4	7.155	3.23
36.35	8.111	3.48
36.8	7.937	3.62
38.15	9.272	3.52
41.11	8.265	
41.12	10.31	3.79
43.3	11.94	3.65
44.5	8.529	3.63
45.0	7.08	3.39
48.0	6.598	3.62
52.9	6.258	3.66
53.05	6.072	3.73
60.2	6.020	3.64
68.8	5.786	3.50
77.5	5.171	3.76
87.8	4.923	3.64

## Cu-Mn

[Cu contained: 0.153O, 0.012 Zn, 0.005Fe, 0.003As, 0.003 (Ni + Co), 0.001(Sb + Sn), tr. (Bi + Mn)];  $t_A = 700^\circ\text{C}$  (198).

Mn	$\rho_A$	$\rho_0$
0.04	1.71	1.75
0.07	1.746	1.79
0.12	1.964	2.01
0.29	2.576	2.62
0.40	2.618	2.72
0.61	3.165	3.25
0.98	4.625	4.83
1.34	5.92	6.09
1.49	6.41	6.66

Mn (135)	$\rho$	$\alpha$
0	1.697	4.28
4.5	17.9	0.17
7.3	19.7	0.32
12.0	36.7	
40	133	
60	164	

Mn (250)	$\rho_{20}$	$\alpha_{20}$
4.2	17.9	0.17
7.4	19.7	0.25

Mn (186)	$\alpha_0$ to 10
0.4	0.97
10	0.09
16	0.14

$t$	20°	22.5°	25°
Mn (147) (10 <sup>6</sup> /ρ <sub>0</sub> )(dρ <sub>0</sub> /dt)			
12	9.09	6.71	4.31
13	8.92	3.48	0.84
14	4.47	1.68	1.12
15	3.93	1.04	1.85

## Cu-Mn.—(Cont'd)

 $\alpha$ , 20 to 100°C (148)

Mn	$\rho_{20}$	$\alpha_{20}$
15	50	0.02
Mn (147)		
13	45	0.00348

## Cu-Mn-Al (63)

(Therlo)  $t = 20$  to  $100^\circ\text{C}$ 

Mn	Al	$\rho_{20}$	$\alpha_0$
13	2	46.5	0.01

## Cu-Mn-Fe (147)

Mn	Fe	$\rho_{22.5}$
10.17	0.286	32.57
12.69	0.329	42.78
14.76	0.327	53.46
18.55	0.401	64.54

## Resistin (160)

13.5	1.9	50.2
------	-----	------

## Cu-Mn-Fe-Si

Mn	Fe	Si	$\rho$	$\alpha$
12.3	0.54	0.26	43.9	
24.95	0.34	0	81.2	0.05
30.0	1.32	0.11	107.3	0.04

## Cu-Mn-Ni-(Fe)

Manganin; v. also Cu-Ni-Mn and Cu-Ni-Fe-Mn  
12% Mn, 4% Ni

$t$	$\rho_t$
(63)	
91.6	47.528
16.25	47.640
+ 0.9	47.636
- 81.9	47.387
- 106.1	47.225
- 197.1	45.820
- 217	45.275

(169)	
+ 17.7	44.6
- 164.0	43.0
- 163.0	43.0
- 154.5	43.1
- 145.3	43.2
- 133.6	43.4
- 119.2	43.9
- 98.5	44.2
- 66.8	44.4
- 50.2	44.5
- 43.6	44.5
- 14.0	44.5
+ 13.8	44.5

(144)	
18	42.0

12% Mn, 3% Ni; 0 to  $10^\circ\text{C}$   
 $\alpha = 0.14$  (90)

Mn (73)	Ni	$\rho$	$\alpha$
24	3	47.7	-0.03
30	0	100.6	+0.04



## Cu-Mn-Ni-(Fe).—(Cont'd)

Mn (131, 234)	Ni	Fe	$\rho_{20}$	$\alpha$
8.84	1.78	0.93	55.6	0.0033
9.93	1.74	0.24	34.2	0.012
10.26	1.77	0.52	37.4	0.015
12.03	3.41	1.04	47.8	0.0022
12.83	2.08	0.73	50.8	0.0038
12.93	2.60	0.82	51.1	0.0057
13.5	2.5	0	37.4	0.016

Other data by (2, 65, 66, 141, 144, 201). Manganin, composition not stated.

$\rho_{15}$	$\alpha$ (°)
Wire	
42.9	-0.024*
41.0 to 43.2	-0.010†
Sheet	
46.0	-0.014*
44.8	-0.008†

\* Range 15 to 97°C.

† Reichsanstalt; range 17 to 53°C for wire, 18 to 60° for sheet.

$t$ (260)	$\alpha$
12.6	+0.006
25	0
50	-0.020
75	-0.035
100	-0.042
125	-0.047
150	-0.050
175	-0.050
200	-0.050
225	-0.050
250	-0.052
275	-0.060
300	-0.057
325	-0.040
350	-0.015
375	+0.010
425	0.040
400	0.060
450	0.055

## Cu-Ni—(Continued)

0 to 370°C (214)

Ni	Co	Fe	$\rho_0$	$\alpha$	$\beta$
9	0.5	1	22	0.570	0.23
20	0	tr.	27.26	0.326	0.69
30	0	tr.	32.35	0.270	0.37
40*	0	0	42.39	0.167	0.047

\* 40% Ni = Constantan.

$\alpha$ , 40 to 70°C (244)			
Ni	$\rho_t$	$t$	$\alpha_0$
3.94	9.0	38.8	1.46
17.3	26.3	54.9	0.30

## Named alloys:

Key	Name
Ae	Advance, v. also Cu-Ni-Fe-Mn
Cn	Constantan, v. also Cu-Ni-Mn

## Cu-Mn-Ni-(Fe).—(Cont'd)

$t$ (260)	$\alpha$
475	0
500	-0.110
525	0
550	+0.150

$\rho_0 = 38.79$ ;  $\Delta_{100} = 0.015$  (201).

Effect of hydrostatic pressure (31). Composition of the commercial manganin is not given.

$r_0$ ,  $[r_p]$  = resistance for  $p = 0$ ,  $[p = p]$ ;  $\Delta = 10^9(r_p - r_0)/r_0 p$ ; unit of  $p = 1 \text{ kg/cm}^2$ .

$p$	$\Delta$	$p$	$\Delta$
1260	2272	9290	2302
2610	2282	8000	2304
3810	2299	6450	2302
5000	2301	4790	2304
6180	2299	3250	2291
7210	2300	1740	2308
8230	2302	1000	2272

Cu-Ni; cf. Cu-Ni-Fe-Mn, and Table 3

$\alpha$ , 20 to 100°C (86)

Ni	$\rho_{20}$	$\alpha_{20}$
0	1.67	4
10	14.6	
20		0.26*
30	38.5	
40	49	
48	49	0.018†
57.5	50.3	0.005
68	50	
100	7	4
	(91)	
2	3	
20	28	
43†	45.0	0.01
46‡	50.2	
50	51	

\* 0.110 (162). † CuNi, from (132).

‡ From (148).

§ From (92),  $t = 0^\circ\text{C}$ .

## Named alloys.—(Cont'd)

Key	Name
Cl	Copel
	Eureka = Constantan
Ia	Ia-Ia
II	Ideal
PN	Patent nickel, v. also Cu-Ni-Fe-Zn-Mn
Re	Rheostatine

## Cu-Ni.—(Continued)

$\rho$	$\alpha$	Lit.
25% Ni; PN		
33.5	0.2	
40% Ni; Cn, Ia		
47-51	-0.04-(+0.03)	(40, 66, 141, 144)
45% Ni; Ae, Cl, II		
49-49.5	NiL-0.01	(65, 130)
48% Ni; Ae, Cn, Ia, Re		
47-49	0.005-0.25	(135)
Composition not given (66, 141, 201); cf. (10, 160, 260)		
44-50	-0.057-(+0.11)	Cn
47-48	0.25-0.27	Re

## Cu-Ni.—(Cont'd)

Ia-Ia (260)

$t$	$\alpha$	$t$	$\alpha$
12.5	0.033	275	0.029
25	0.030	300	0.035
50	0.022	325	0.030
75	0.015	350	0.030
100	0.006	375	0.028
125	0.006	400	0.028
150	0.005	425	0.035
175	0.009	450	0.067
200	0.010	475	0.110
225	0.015	500	0.200
250	0.020		

## Cu-Ni-Al; v. Cu-Al-Ni

Cu-Ni-Co-Fe-Zn; v. Cu-Ni-Fe-Co-Zn

## Cu-Ni-Cr (135, 250)

Ni	$\rho_{20}$	$\alpha$
4.76% Cr		
0	2.1	3.45
23.84	25.1	0.35
47.62	55.1	0.14
71.4	70.5	0.41
95.24	45.7	0.97
9.1% Cr		
0	2.2	3.49
22.7	22.4	0.42
45.45	50.7	0.18
68.2	83.9	0.16
77.3	86.3	
90.9	67.8	0.37
13.04% Cr		
0	3.4	2.5
21.76	22.1	0.47
65.2	86.4	0.11
73.9	99.0	
78.2	95.7	
86.96	84.1	0.20

## 16.7% Cr

Ni	$\rho_{20}$	$\alpha$
0	2.7	2.99
20.8	21.3	0.46
41.6	36.7	0.31
62.5	86.3	0.12
66.7	108.7	
70.8	109.8	
70.8	112.9	0.078
75	106.4	
75	106.3	0.079
79.1	98.3	

## Cu-Ni-Cr.—(Cont'd)

Ni	$\rho_{20}$	$\alpha$
16.7% Cr		
83.3	95.9	
83.3	96.9	0.12
20% Cr		
64	121.8	
67	110	
67	111.6	
72	107	

Ni (249)	Cr	$\rho_t$	$t$	$\alpha$
62.5	16.7	86.3	18.2	0.12
65.1	13.15	86.4	20.6	0.11
68.2	9.1	83.9	18.6	0.16
71.4	4.8	70.5	22.6	0.41
82	12	85*		0.3*

\* From (148).

## Cu-Ni-Fe-x

Excelsior (66, 141)

Cu, 53; Ni, 45; Fe; x

$\rho_0$	$\alpha$ at 17°
II 5.79	1.42
I 80.29	0.95

## Cu-Ni-Fe-Co; v. Cu-Ni

## Cu-Ni-Fe-Co-Zn

Silverine (63)

Ni = 17%, Fe = Co = Zn = 2%

$t^*$	$\rho_t$
-197.1	0.909
-106.1	1.452
-81.9	1.582
0.0	2.064
+0.95	2.071
16.25	2.166
+90.9	2.614
$\alpha_{15} = 2.85$	

\* Pt-scale of  $t$ .

## Cu-Ni-Fe-Mn; v. also Cu-Ni-Fe-Mn-(Si, C)

Ni (155)	Fe	Mn	$\rho_0$	$\alpha_0$
0.00			1.53	3.77
10.04	0.15	tr.	14.6	0.49
16.01	0.18	tr.	21.6	0.31
20.04	0.13	tr.	26.4	0.27
24.07	0.58	0.02	31.3*	0.21
29.94	0.36	0.36	38.4	+0.12



## Cu-Ni-Fe-Mn.—(Cont'd)

Ni (155)	Fe	Mn	$\rho_0$	$\alpha_0$
41.25	0.37	0.70	50.0	-0.032
46.18	0.32		52.2	-0.080
49.36	0.54	0.32	51.7	+0.040
50.84	0.38	0.65	51.7	0.055
56.37	0.34	tr.	52.5	0.15
62.02	0.34	tr.	51.5	0.16
89.46	1.19	1.40	19.0	3.00
93.66	1.02	1.45	16.6	2.90
100.00			12.3	3.47

\* 0.70 % Zn.

Advance (65, 134, 260); v. also

## Cu-Ni

Ni	Fe	Mn	$\rho_{20}$	$\alpha$
44	0.5	1.0	48.8	ca. 0.01
44	0.45	1.16	48.2	0.02

$t$ (134)	$\rho$	$t$ (134)	$\rho$
20	48.24	400	48.51
100	48.20	500	49.20
200	48.22	600	50.11
300	48.31		

$t$ (260)	$\alpha$	$t$ (260)	$\alpha$
12.5	+0.020	300	0.027
25	+0.005	325	0.030
50	-0.008	350	0.030
75	-0.012	375	0.033
100	-0.007	400	+0.025
125	-0.004	425	-0.010
150	0	450	+0.020
175	+0.003	475	0.040
200	0.007	500	0.080
225	0.010	525	0.105
250	0.014	550	0.105
275	0.020		

## Cu-Ni-Fe-Zn-Mn (73, 74), Patent nickel; v. also Cu-Ni

Ni	Fe	Zn	Mn	$\rho$	$\alpha$
24.14	0.70	0.52	0.17	32.8	0.21
25.1	0.42	0.23	0.13	34.2	0.19

## Cu-Ni-Fe-Mn-(Si, C), Monel metals

67Ni, (Fe + Mn + Si) = ca. 5 (136)

$t$	$\rho$	$t$	$\rho$
20	44.68	100	51.4
30	45.57	110	51.8
40	46.53	120	52.2
50	47.50	130	52.5
60	48.45	140	52.86
70	49.4	150	53.1
80	50.3	160	53.32
90	50.9		

$\rho_{20}$	$\alpha_{20}$
43.5	0.022
44.9*	1.9*

\* From (65).

68.10Ni, 2.4Fe, 1.5Mn, 0.11Si, 0.16C (134)

$t$	$\rho$	$t$	$\rho$
20	44.56	600	61.70
100	51.69	700	63.92
200	54.13	800	66.16
300	55.91	900	69.05
400	57.70	1000	72.65
500	59.70		

 $\rho = 42.6$ ;  $\alpha = 1.98$  (207).  
68Ni, 2.5Fe, 1.5Mn (65)

$\rho_{20}$	$\alpha_{20}$
42.5	1.9

## Cu-Ni-Mn.—(Cont'd)

$t$ (260)	$\alpha$
12.5	+0.008
25	+0.002
50	-0.014
75	-0.028
100	-0.033
125	-0.033
150	-0.030
175	-0.027
200	-0.020
225	-0.020
250	-0.017
275	-0.015
300	-0.015
325	-0.013
350	-0.012
375	-0.007
400	0
425	+0.007
450	0.014
475	0.017
500	0.027
525	0.047
550	0.100

## Cu-Ni-Mn.—(Cont'd)

65Ni, 5Mn (Lucero) (65);  $\rho_{20} = 46.6$ ;  $\alpha = 0.76$   
67Ni, 2.60Mn (112); for  $t_A = 650^\circ$ ,  $\Delta_H = 7.7$ 

## Cu-Ni-Mn-Fe; v.

## Cu-Ni-Fe-Mn

## Cu-Ni-Ti, Wire (132)

Ni	Ti	$\rho$
16	1	23
41	2	52.5
22	3	31.5
48.5	3	53.3
62*	3	63.2
73	3	61.7
40	4	51.7
55	4	58.7
71	5	60.3

\* For 63 % Ni,  $\alpha = 0.267$ .Cu-Ni-Zn (112); v. also Ni-Cu-Zn and Cu-Ni-Zn-(Co, Fe, Mn)  
 $t_A = 650^\circ\text{C}$ 

Ni	Zn	$\Delta_H$
13	20.3	-1.5
23.24	18.9	+6.7

## Cu-Ni-Zn-(Co, Fe, Mn)

German silvers;  $t = 15$  to  $17^\circ\text{C}$ ;  $t_A = 797^\circ\text{C}$ ; 55-62% Cu (276)

Ni	Zn	Mn	$\rho_H$	$\rho_A$	Key
28.6	9.8	0.0	41.5	41.3	A
22.4	15.85	0.0	32.6	34.0	B
16.4	21.7	0.0	30.2	29.8	C
17.4	26.7	0.0	27.5	27.6	D
7.62	31.7	0.0	22.2	19.2	E
27.9	11.4	0.25	38.5	39.1	F
19.8	18.5	0.25	29.5	31.5	G
15.5	23.2	0.25	27.5	28.0	H
15.75	29.7	0.25	27.7	28.3	I
7.80	31.8	0.25	18.3	17.2	J
26.7	13.15	1.5	38.5	39.8	K
16.3	27.6	1.5	30.4	31.8	L

Variation with  $t_A$ 

Key	A	B	C	D	E
$t_A$	$\rho_A$ (Mn = 0)				
100	41.6	32.8	30.5	27.7	21.6
245	41.6	32.3	30.0	27.9	22.0
293	42.0	32.5	30.4	28.0	21.1
332	42.2	33.8	31.5	28.6	20.7
353	41.7	34.2	31.5	28.4	19.3
381	41.5	34.5	31.8	28.0	18.8
405	40.9	32.6	30.6	27.5	18.3
430	40.9	32.5	30.0	27.4	18.2
453	41.0	33.5	30.5	26.8	17.9
470	40.9	33.9	30.0	27.5	18.3
500	41.0	33.0	30.1	27.0	18.4
538	40.9	33.5	30.5	27.3	18.6
590	40.9	33.9	30.8	27.7	19.0
646	41.1	33.1	30.3	27.1	19.5
696	41.1	33.5	30.4	27.5	19.5
797	41.3	34.0	29.8	27.6	19.2

## Cu-Ni-Mn (250)

Ni	$\rho_{20}$	$\alpha_{20}$
4.8% Mn		
0	17.9	0.17
19.0	33.5	0.14
38.1	50.4	0.089
47.6	55.1	0.085
57.1	54.35	0.22
66.6	50.72	1.09
76.2	38.8	2.39
95.2	17.4	2.97
7.4% Mn		
0	19.7	0.32
18.5	40.2	0.075
37.0	54.8	0.071
46.4	58.1	0.088
55.5	60.05	0.14
64.8	55.8	0.53

## Cu-Ni-Mn.—(Cont'd)

Ni	$\rho_{20}$	$\alpha_{20}$
7.4% Mn		
74.1	45.8	1.85
92.6	23.3	2.49
13.1% Mn		
26.1	62.1	-0.026
34.8	68.7	-0.016
43.5	70.8	+0.025
52.1	75.3	+0.064
40-55Ni, 0-1.4Mn, 0.1C (Constantan); v. also Cu-Ni		
$t$ (245)	$\rho/\rho_0$	
0	10 000	
-76.4	9 982	
-185.8	9 898	
-252.9	9 784	



## Cu-Ni-Zn-(Co, Fe, Mn).—(Continued)

Key	F	G	H	I	J
$t_A$	$\rho_A$ (Mn = 0.25)				
100	38.0	29.5	27.2	27.5	18.2
245	38.4	29.3	27.7	27.7	18.2
293	38.5	30.1	27.8	28.4	18.0
332	39.0	30.9	29.0	29.5	18.1
353	39.0	31.7	29.1	29.5	17.7
381	38.9	31.9	29.0	29.5	16.6
405	39.0	32.0	28.2	28.3	16.5
430	38.3	29.6	28.1	28.0	16.7
453	38.5	31.8	28.1	28.1	16.7
470	38.8	32.2	27.9	27.5	16.7
500	38.7	31.6	27.2	28.3	16.9
538	38.6	32.0	27.7	28.1	16.6
590	39.0	32.4	27.9	28.6	16.8
646	38.8		27.8	28.0	16.6
696	38.7	31.5	27.7	28.0	16.6
797	39.1	31.5	28.0	28.3	17.2

Key	K	L	Key	K	L
$t_A$	$\rho_A$ (Mn = 1.5)		$t_A$	$\rho_A$ (Mn = 1.5)	
100	38.1	29.5	453	39.5	31.5
245	38.9	30.5	470	39.5	31.1
293	38.0	30.7	500	40.0	30.8
332	39.0	32.5	538	39.4	31.0
353	39.5	32.8	590	39.2	31.5
381	39.5	33.2	646	39.8	31.4
405	39.6	32.1	696	39.8	30.9
430	39.6	31.0	797	39.8	31.8

50% to 63% Cu; Argentan (A), German silver\* (G), Maillechort (M), Nickeline\* (N), Nickel silver (S), Platinoid (P), Rheotan (R); approximately 62Cu, 22Zn, 15Ni (153)

German silver				Platinoid			
$t$	$\rho$	$t$	$\rho$	$t$	$\rho$	$t$	$\rho$
+ 17.2	39.8	-116.1	38.3	+ 21.2	34.4	-99.5	33.1
-169.1	38.0	-105.3	38.4	-171.0	32.4	-96.4	33.1
-168.2	38.0	- 95.5	38.6	-173.0	32.3	-92.1	33.3
-159.3	38.0	- 57.2	39.0	-172.0	32.4	-71.0	33.3
-153.0	37.9	- 53.3	39.1	-160.2	32.3	-66.6	33.5
-145.8	37.9	- 50.9	39.1	-155.0	32.4	-35.0	33.7
-134.6	38.0	- 16.0	39.5	-146.7	32.6	-24.4	33.8
-126.9	38.1	+ 16.5	39.8	-134.6	32.8	+10.0	34.3
				-103.9	33.0	+10.5	34.3

\* German silver,  $\rho_0 = 42.9$ ,  $\alpha_0 = 0.038$ ; Nickeline,  $\rho_0 = 27$  to 43,  $\alpha_0 = 0.024$  to 0.34; composition not stated (66, 141).

	Ni	Zn	Fe	Mn	$\rho_0$	$\alpha_0$	Lit.
G	15	22			26.6	0.38	(144)
P	15	22			34.2	0.32*	(169)
GM	14	25	0.3		30.0	0.36	(73, 74)
N	18.5	20	0.24		33.2	0.30	(73, 74)
G	18.5	31.1			30.0	0.27	(63); cf. (76)
N	24.5	20.4	0.64		44.8	0.33	(73)
N					36.2	0.22	(201)
P	25	20.4	0.5	0.15	41		(160)
R	25	16.9	4.46	0.37	52.5	0.41	(73)
R	25	17	5		47.6	0.24	(66, 141)
R					44.65	0.28	(201)
A	26	18	( $t = 15^\circ$ )		42.0		(65)
A					28.45	0.33	(201)
S	18	27	( $t = 20^\circ$ )		30	0.27	(65)
S	18	(?)	( $t = 20^\circ$ )		33	0.31	(135)

\* From 0 to  $-173^\circ\text{C}$ . For wire,  $\rho_{18} = 34.4$ ,  $\alpha_0 = 0.25$  for 18 to  $-160^\circ\text{C}$  (144). cf. (141, 169).

Cu-Ni-Zn-(Co, Fe, Mn).—(Continued)  
40% to 56% Cu, German silvers; 0 to  $370^\circ\text{C}$  (214)

Ni	Zn	Fe	Co	$\rho_0$	$\alpha_0$	$\beta_0$
32	16			25.26	0.26	1.3
23	19		tr.	22.52	0.28	5.2
18	24		2	30.87	0.043	0.28
30	26	tr.	4	47.61	0.043	0.80

## Cu-P

[Cu contains: 0.1530, 0.012Zn, 0.005Fe, 0.003As, 0.003(Ni + Co), 0.001(Sb + Sn), tr. (Bi + Mn)];  $t_A = 700^\circ\text{C}$  (198).

P	$\rho_0$	$\rho_A$
0.011		1.71
0.040	2.09	2.12
0.092	2.51	2.508
0.173	3.07	3.237
0.399	5.23	5.59
0.563	7.24	7.94
1.062	12.66	13.32

For Cu,  $\rho_{18} = 1.78$  (228)

P	$\rho_{18}$	P	$\rho_{18}$
Rod		Sheet	
0	1.78	0	1.78
0.13	2.45	0.30	3.27
0.34	4.85	0.76	6.12
0.87	8.55	1.19	8.36
1.79	13.7	1.56	9.95
2.35	17.6	1.73	10.53
2.5	22.9	3.15	20.2
5.25	31.8		

For Ag,  $\rho_0 = 1.54$ ; Dd wire (186, 188, 189)

P	$\rho_0$	$\alpha_0$	$\beta_0$
0.13	2.28		
0.95	6.59	1.32	0.10
2.5	20.84	0.48	0.04

## Cu-Pb; v. Table 3

## Cu-Sb; v. also Table 3

Sb	$\rho$	(96)
48.6	8.3	Cu <sub>2</sub> Sb
65.4	20	CuSb

## Cu-Sb-O (87)

Sb	O	$\rho_{18}$
0.14	0.08	1.86
0.13	0.27	1.87
0.18	0.31	1.93
0.39	0.10	2.60

Cu-Sn; v. also Table 3  
Bronze, 12% Sn; v. also Cu-Sn-Zn-Pb (167, 172)

Sn	$\rho_0$	$\Delta_{100}$
4.1	8.2	1.08
8.3	10.4	1.14
9.7	15.5*	0.109†
12.6	18.0	0.8
12.6	17.3*	

## Cu-Sn.—(Cont'd)

Sn	$\rho_0$	$\Delta_{100}$
17.2	21.7	+0.51
21.4	29.4	-1.49
25.95	32.5	-0.03
30.15	41.8	+0.46
31.7	48.3*	
35.3	15.32	1.32
38.2	11.12*	
40.1	8.75	2.82
44.9	11.1	2.7
50.0	12.2	2.15
55.1	11.7	2.4
60.25	12.1	2.42
65.6	12.95	2.76
71.1	13.3	2.96
77.5	13.4	3.84
80.8	13.15*	
82.2	12.9	3.54
88.1	12.8	3.07
94.0	12.4	4
100.0	12.8	4.5
100.0	12.0*	

\* From (172). † For 10% Sn (182).

[Cu contains: 0.1530, 0.012Zn, 0.005Fe, 0.003As, 0.003(Ni + Co), 0.001(Sb + Sn), tr. (Mn + Bi)];  $t_A = 700^\circ\text{C}$  (198)

Sn	$\rho_A$	$\rho_0$
0.13	1.955	2.01
0.24	2.096	2.16
0.32	2.459	2.47
0.40	2.542	2.57
0.53	2.542	2.61
0.62	2.73	2.86
0.88	2.96	3.00
1.15	2.99	3.09
1.24	3.495	3.5
1.46	3.645	3.74

Dd wire (186); For Ag,  $\rho_0 = 1.54$

Sn	$\rho_0$
1.31	3.17
2.46	4.72
4.67	7.91

Sn	$\rho_t$	$t$	Lit.
5.	10.11	49.6*	(244)
38.5	33.3	Cu <sub>4</sub> Sn	(96)
48.3	11.1	Cu <sub>3</sub> Sn	(96)
65.1	13.3	CuSn	(96)
7.3	$\Delta_H^\dagger = +4.1\%$		(112)

\*  $\alpha_0 = 1.06$ , 50 to  $90^\circ\text{C}$ .

†  $t_A = 675^\circ\text{C}$ .



## Cu-Sn.—(Cont'd)

Sn (188, 189)	$\rho_0^*$	$\alpha_0$	$\beta_0$
1.15	2.45	2.68	2.14
5.16	7.77	1.00	0.29
8.91	12.63	0.76	+0.24
9.55	15.08	0.67	-0.74
12.5	17.24	0.55	+0.005
80.6	11.81	3.33	6.85
92.2	12.52	3.68	5.44

\* Assumes for Ag,  $\rho_0 = 1.54$ .

## Cu-Sn-P (217)

Sn	P	$\rho_A$	$\rho_{Td}$
5.08	0.01	10.5	10.5

## Phosphor bronze wire

Sn	P	$\rho_0$	$\alpha_0$
2	(?)*	5	-6
0.2	(?)*	1.7-2	3-4

\* Content not stated.

## Cu-Sn-Pb (186)

Sn	Pb	$\rho_0$
0	0	1.835
0.1	0	1.70
0.1	0.1	1.72

## Cu-Sn-Si, Silicon bronze wire

Sn	Si	$\rho_0$	$\alpha_0$
1.5-9	0.05	1.7-3.9	2.3-3.8

## Cu-Sn-Zn-Fe-(P), 0.01% P (217)

Sn	Zn	Fe	$\rho_A$	$\rho_{Td}$
14.42	tr.	0.06	20.2	21.2
10.02	0.21	0.05	15.8	16.6

Sn (202, 216)	Zn	Fe	P	$\rho_A$	$\rho_{Td}$
5.08	0	0	0.01	10.5	10.5
10.02	0.21	0.05	0.01	15.8	16.6
14.42	tr.	0.06	0.01	20.2	21.2
19.16	0.43	0.13	0	25.9	27.0

## Cu-Sn-Zn-Pb, Bronze; v. also Cu-Sn

Sn	Zn	Pb	$\rho_{18}$
6	4	1	13.5

## Cu-Ti wire (132)

Ti	$\rho$	$\alpha$
1	22.38	0.292
2	35.51	2.440
5	57.2	

## Cu-Zn, for molten alloy, v. Table 3

Zn	$\rho_0$	$\Delta_{100}$
(222)		
0	1.538	4.43
3.15	2.392	3.02
5.2	3.188	2.34
8.3	4.029	2.14
30.6	6.866	1.60

## Cu-Zn.—(Cont'd)

Zn	$\rho_0$	$\Delta_{100}$
32.2	7.029	1.59
35.65	6.957	1.63
38.65	6.808	1.71
42.7	5.558	2.51
43.7	5.420	2.65
45.7	4.682	3.00
48.7	4.291	3.39
50.0	4.137	3.57
50.7	4.330	3.55
50.7	4.302*	3.64
53.7	6.000†	3.16
58.7	11.28	2.22
59.7	13.01	2.08
60.7	12.10	2.34
61.7	11.31	2.50
62.65	11.00	2.54
65.65	10.25	2.90
65.65	10.30	3.00
67.35	9.812	4.08
69.6	9.533	3.57
70.6	9.226	3.61
71.6	8.597	3.31
72.6	8.460	3.02
72.6	8.252	3.22
75.55	8.050	2.74
77.55		2.53
78.5	7.491	2.42
80.5		2.42
81.5	6.864	2.57
83.45	8.972	2.77
84.4	10.42	3.07
85.4	11.56	3.20
86.1	11.75	3.51
86.4	10.71	3.29
86.85	9.704	3.20
88.3	7.451	
89.3	7.100	3.25
90.25	6.555	3.58
91.35	6.362	3.47
92.2	6.420	3.44
93.2	6.419	3.50
95.15	6.403	3.58
97.1	6.306	3.79
100.0	6.154	4.27

## (202)

2.48	2.675	2.92
7.45	3.875	1.891
11.65	4.51	1.862
15.0	4.92	1.869
19.05	5.74	1.852
26.8	6.08	1.767
28.75	6.16	1.750
34.15	6.72	1.676
36.3	6.8	1.474
42.1	5.875	1.635
47.5	4.52	2.320
53.8	5.28	1.933
57.7	11.8	2.086
63.3	8.1	1.754
68.9	8.62	3.341
75.3	8.54	2.615
76.3	7.67	1.793
82.4	8.17	2.51

## Cu-Zn.—(Cont'd)

Zn	$\rho_0$	$\Delta_{100}$
88.25	7.65	2.778
92.25	6.08	3.351
93.8	6.2	3.361
(117)		
0	1.576	4.316
0	1.592	4.328
0.71	1.823	3.725
1.56	2.133	3.185
3.07	2.372	2.913
5.51	3.010	2.383
9.08	3.628	2.044
18.02	4.763	1.691
20.29	5.064	1.639
22.71	5.424	1.607
28.16	5.826	1.581
34.23	6.302	1.579
40.28	5.789	2.116
42.55	5.307	2.376
45.19	4.712	2.851
46.85	4.314	3.105
99.53	5.883	3.847
100.00	5.683	4.029

\* CuZn; Guertler (26) gives  $\rho = 3.1$ .† For 55.7% Zn,  $\rho_{21} = 8.181$ .

Zn (244)	$\rho_t$	$t$	$\alpha_0^*$
3.11	2.84	41.5	3.06
5.00	3.83	38.5	2.72

\* 40 to 70°C.

Zn (188, 189)	$\rho_0^*$	$\alpha$	$\beta$
4.05	2.54	2.471	2.01
8.89	3.26	2.04	1.56
19.8	5.43	1.42	0.65
25.0	6.98	1.27	0.38
36.7	6.91	1.37	0.55

\* Assumes for Ag,  $\rho_0 = 1.54$ .Brass rod, Zn = ca. 30%,  $D = 1.40$  if  $-180^\circ < t < 22^\circ$  (169)Brass wire, Zn = 33%,  $\Delta_{Hm} = 5.7$ ;  $\rho_A = 6.61$ ;  $\rho_{Hm} = 6.99$  (111)Brass (112);  $t_A = 650^\circ\text{C}$ 

Zn	$\Delta_H$	Zn	$\Delta_H$
8.3	+3.6	32.1*	+21.8
18.2	+11.4	39.7	+16.5

\*  $\Delta_H$  varies from 6.5 to 21.8% depending upon the amount of hardening.Cu-Zn-Fe;  $t = 20^\circ\text{C}$ 

Zn	Fe	$\rho_A$	Lit.
39.52	0.13	6.30	(113)
49.8	0.13	5.0*	(217)

\*  $t_A = 650^\circ\text{C}$ . Cast = 4.6,  $Q_{700} = 5.8$ .

## Cu-Zn-Ni; v. Cu-Ni-Zn

Cu-Zn-Ni-(Co, Fe, Mn); v. Cu-Ni-Zn-(Co, Fe, Mn)			
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## Cu-Zn-Pb (113); v. also Table 3

Zn	Pb	$\rho_A$	$\rho_{Bo}$
31.86	0.13	6.47	7.88*

\* Drawn to 1.5 mm and cold rolled to sectional area = 1.17 mm<sup>2</sup>; previous annealing reduces effect of rolling.Fe;  $\rho_{18} = 9.66$  (146)

For effect of stress and of magnetic field, v. Fe-Ni

## Fe-x

The substance x is indicated by its symbol;  $t = 18^\circ\text{C}$ ; Gh = Gumlich, Bs = Benedicks, Bt = Barrett, Mr = Mahler; all as quoted by Stäblein (262).

$\delta$		Lit.
Al		
$\delta_1$	11.6	Gh
	11.8	Bs
	14	Bt
$\delta_2$	28	(9)
	25.5	(13)
$\delta_3$	36	(9)
$\delta_4$	44.5	(13)
$\delta_5$	54	(9)
$\delta_6$	61.5	(13)
B		
$\delta_1$	6.2	(298)
C*		
$\delta_1$	-1.74	(146)
	+13.3	(298)
Dissolved C		
$\delta_1$	3.4	Gh
	0.0	Bs
	(5)	Bt
	7	Mr
Free C		
$\delta_1$	29	Gh
	26.8	Bs
Cr		
$\delta_1$	6.2	Bs
	5	Bt
$\delta_2$	10	(9)
$\delta_3$	11.5	(9)
$\delta_4$	12.0	(12)
$\delta_5$	14	(9)
$\delta_6$	14.0	(13)
Cu		
$\delta_1$	-0.18	(146)
	+5.5	Gh
	5.1	Bs
	4	(45)
	4	(236)
Mn*		
$\delta_1$	6.27	(146)
	4.7	Gh
	5.9	Bs
	8	Bt
	5	Mr
	5.5	(178)
$\delta_2$	16	(9)
	15.0	(13)
$\delta_3$	18	(9)
$\delta_4$	21.0	(13)



Fe-x.—(Cont'd)		
$\delta$		Lit.
<b>Mn.*—(Cont'd)</b>		
$\delta_5$	24.5	(9)
$\delta_5$	26.0	(13)
<b>Ni</b>		
$\delta_1$	1.46	(146)
	5.5	Bs
	3.5	Bt
	1.7	(123)
$\delta_2$	7	(9)
	6.5	(13)
$\delta_3$	9	(9)
$\delta_4$	10.0	(13)
$\delta_5$	13	(9)
$\delta_6$	12.5	(13)
<b>P*</b>		
$\delta_1$	10.09	(146)
	11.2	Gh
	10.3	Bs
	11.0	(4)
<b>S*</b>		
$\delta_1$	1.80	(146)
	10.9	Gh
	10.0	Bs
<b>Si*</b>		
$\delta_1$	20.26	(146)
	13.3	Gh
	11.3	Bs
	13	Bt
	13†	(299)
	11†	(299)

Fe-x.—(Cont'd)		
$\delta$		Lit.
<b>Si.*—(Cont'd)</b>		
$\delta_2$	26	(9)
$\delta_3$	34	(9)
$\delta_4$	41.0	(13)
$\delta_5$	49	(9)
$\delta_6$	55.5	(13)
<b>W</b>		
$\delta_1$	1.75	Bs
	2	Bt
$\delta_2$	4	(9)
	4.0	(13)
$\delta_3$	5	(9)
$\delta_4$	5.5	(13)
$\delta_5$	6	(9)
$\delta_6$	6.0	(13)

\* If symbol of  $x$  indicates the Wt. %, then for  $C \leq 0.02$ ,  $Mn \leq 1$ ,  $P \leq 0.015$ , and  $S \leq 0.1$ ,  $\rho_{20} = 9.6 + 7Mn + 128 + 60P + 82.5C$ ; for  $Si \leq 0.35$ ,  $\rho = 9.6 + 18.4 Si$ , for  $0.35 \leq Si \leq 6.5$ ,  $\rho = 16.05 + 11.1 (Si - 0.35)$  (302, 304).

† 11 to 13.

**Fe-(C, Mn, P, S, Si)**  
If  $C_i$  = Wt. % of total impurities, then, roughly,  $\rho = 8 + 7.5C_i$  if  $C_i$  lies between 0.4 and 1.9; deviations of 15% or 20% are recorded (52).

Fe-(P, S, Se, C) Elec. Fe; $\frac{1}{1000}\%$ (305)					
S	C	C*	$\rho_A$	$t_A$	
	3		10.25	920	vac
	16	4	9.91	905	vac
17			9.93	950	air
10	25		10.15	950	
19	14	8	10.28	910	vac
13	20	16	10.81	910	vac
10	30	21	11.43	910	vac
12	76	61	11.47	920	vac
S	P	C*	$\rho_A$	$t_A$	
35			10.3	923	vac
36			10.4	923	vac
40			10.3	923	vac
60			10.65	923	vac
68			10.55	923	vac
28			12.55	922	vac
29			11.34	922	vac
36			11.0	922	vac
21	10		10.8	924	vac
16	19	0.8	10.35	924	vac
23	33	1.5	10.45	924	vac
20	37	1.1	10.8	924	vac
20	41	1.6	10.85	924	vac

\* After annealing.

Fe-(P, S, Se, C).—(Cont'd)		
$\frac{1}{1000}\%$ (46)		
Se	17	19
$\rho_{Tp}$	16.2	14.6
$t_{Tp} = 900^\circ\text{C}$		
Fe-Ag (46); $t_{Tp} = 900^\circ\text{C}$		
Ag	$\rho_{Tp}$	
0.281	12.5	
0.492	13.3	
0.506	13.6	
0.533	13.1	
0.581	14.7	
0.677	13.5	
0.691	13.8	
4.0	7.7*	

\*  $A_{1000}$ ;  $\rho_{Hm} = 12.2$ .

**Fe-Al**  
At  $18^\circ\text{C}$ ,  $\delta_2 = 23$ ,  $\delta_3 = 36$ ,  
 $\delta_5 = 54$  (9)

Al	$\rho$
$A_{1100}$ ; $20^\circ\text{C}$ ; $C \leq 0.16\%$ (306)*	
0	10.3
0.09	11.0
0.1	11.8
0.73	18.0
1.55	29.4
3.31	43.9
3.53	49.0
4.83	57.7
5.30	67.7
8.10	81.4
8.60	84.3
Treatment (?) (158.1)	
10	100
$Tp_{900}$ (46)	
0.067	23.9
1.333	17.4

0.8% Al

$\rho_{Hm} = 20.6$

$\rho_A = 16.1$

$t_A = 1000^\circ\text{C}$

\*  $\rho$  is unaffected by heat treatment; same for F,  $A_{900}$ , and  $A_{1100}$ ;  $C \leq 0.06\%$ , excepting for Al = 4.83, 8.10, 8.60, for which  $C = 0.16, 0.09, 0.13\%$ , respectively.

Fe-Al-C		
Al	C	$\rho_N$
$t = 20$ to $23^\circ\text{C}$ ; $t_H = 975^\circ\text{C}$		
$\rho_H - \rho_N = \text{ca. } 1.0$		
(219)		
0.51	0.09	17.1
1.08	0.11	26.3
2.04	0.17	35.9
3.05	0.13	50.7
5.08	0.17	63.6
7.18	0.08	76.6
$t = 19$ to $23^\circ\text{C}$ ; $t_H = 975^\circ\text{C}$		
$\rho_H - \rho_N = \text{ca. } 1.0$		
1.05	0.67	30.3
2.09	0.80	47.4
2.89	0.69	53.0
4.65	0.81	65.6
9.15	0.66	92.6
14.90	0.87	87.8

Fe-Al-Cr-C (12, 13)				
$t = 18^\circ\text{C}$ ; $t_A = 1000^\circ\text{C}$				
Al	Cr	C	$\rho_A$	$\rho_O$
0.75	1.75	0.21	28.0	33.2
1.00	3.50	0.46	45.0	49.9
2.50	1.50	0.18	50.3	58.5
4.50	1.50	0.22	68.4	77.8
$\rho_O - \rho_A = \text{ca. } 0.15\rho_A$				

Fe-Al-Si-C (12, 13)				
$t = 18^\circ\text{C}$				
Al	Si	C	$\rho_A$	$\rho_O$
0.75	0.10	0.17	22.0	24.8
2.25	0.18	0.24	39.0	46.3
5.50	0.20	0.22	70.0*	71.8
* $\rho_D = 74.6$ ; $\alpha_D = 0.63$ for 0 to $150^\circ\text{C}$ .				

Fe-Al-Sn (46)			
Al	Sn	$\rho_A^*$	$\rho_{Hm}$
2	1	18.2	18.9
* $t_A = 1000^\circ\text{C}$ .			

Fe-As (46)	
As	$\rho$
$Tp_{900}$	
0.292	14.7
0.430	16.8
0.915	19.5
1.81	25.5
3.862	37.1
3.563	34.0
$A_{1000}$	
1.0	14.3
3.0	26.1
5.0*	20.8
$Hm$	
1.0	18.1
3.0	25.3
5.0	26.7

\* Adding 5% As to transformer iron ( $A_{1000}$ ) increases  $\rho$  from 18.7 to 30.2.

Fe-As-Mn-Cu-P	
0.4Mn, 0.2Cu, 0.2P, 0.05S, 0.05Si, 0.08C (170)	
As	$\rho$
0.123	13.3
0.277	14.2
0.405	15.3
0.459	15.8
0.691	16.8
0.880	18.4
1.172	20.6
1.425	21.9
1.621	23.4
1.943	25.2
2.240	27.3
2.534	27.5
2.841	29.1
3.130	31.6
3.284	37.9
3.515	35.3



Fe-Au (102); v. also Au-Fe and figure on p. 203

Au	$\rho_0$	$\alpha_0$	$\beta_0$
0	11.0	5.3	3.4
1	11.9	4.9	3.4
3	14.3	4.1	3.0
5	16.3	3.6	3.1
10	19.7	3.0	2.8
20	17.0	3.6	3.5
40	20.0	3.3	3.3

Fe-B (298);  $\delta_1 = 6.2$

Fe-B-C, Boron steel (219)

B	C	$\rho_{25}$
0.21	0.18	17.1
0.48	0.22	22.9
0.84	0.21	29.0
0.15	0.47	29.1*
0.41	0.59	29.8*

\*  $Q_{100}$ .

Fe-Bi;  $A_{1000}$  (46)

Bi	$\rho$
1.0	13.4
2.0	14.5
4.0	15.3
6.0	13.0
10.0	16.6

Fe-C; v. also Table 3

For pure Fe,  $\delta_1 = 13.3$  (298);  $\delta_1 = -1.74$  (146)

Steels

(213)	C	Si	$\rho_0$	$\alpha_0$	$\beta_0$
Ss*	3	tr.	13.50	3.7	7.4
S*	4	0.1	11.75	3.5	4.3
Sh*	6	tr.	11.25	4.9	8.9
H*	8	0.1	15.42	4.0	5.4

Electrolytic Fe (305)

C	C*	$\rho_A$	$t_A$	
0.016	0.004	9.91	905	vac
0.003		10.25	920	vac
0.176		12.58	936	vac
0.206		12.29	936	vac
0.205		12.55	930	vac
0.282		11.82	930	vac
0.284		12.2	930	vac
0.224	0.235	12.0	900	N <sub>2</sub>
0.224	0.151	12.4	900	vac
0.315	0.339	12.7	900	N <sub>2</sub>
0.315	0.227	13.4	900	vac
0.492	0.485	13.5	900	N <sub>2</sub>
0.492	0.387	13.9	900	vac
0.742		13.8	900	N <sub>2</sub>
0.742	0.559	14.2	900	vac
0.846	0.85	14.7	900	N <sub>2</sub>
0.846	0.791	15.65	900	vac
1.016	0.985	18.7	900	vac
1.016	0.981	18.5	900	vac

\* After heat treatment.

Fe-C.—(Cont'd)  
Mn, 0.2; Si, 0.1;  $t \geq 800^\circ\text{C}$   
(25)

	C	$\rho_{800}$	D
M*	0.205	42.8	4.86
Sh*	0.493	47.0	4.3
H*	0.841	72.7	2.3
H*	0.82	92.9	2.8
H*	1.05	92.0	2.9
H*	1.16	90.6	2.83
H*	1.38	97.75	3.01

\* Ss = very soft; S = soft; Sh = semi-hard; H = hard; M = mild.

Semi-hard steel (161); 0.06C, 0.4Mn

t	$\rho$
15	20.4
300	54.8
420	70
600	101.9
700	123.5
820	163
960	168
1100	170.6

Hard steel (161)

t	$\rho$
15	30.6
280	58.6
410	76.4
680	135
730	144
830	177
870	182
940	185.9
1050	188.4

Fe-C.—(Continued)  
Swedish iron + C (127)

t	$\rho_t$	t	$\rho_t$	t	$\rho_t$	t	$\rho_t$
0% C		0.18% C		0.44% C		0.80% C	
3	15.3	781	102.4	420	56.6	684	110.3
9	20.0	746	97.1	302	44.6	677	106.8
140	23.1	731	93.6	0.64% C		676	102.3
183	26.3	723	91.6	24	16.5	1.02% C	
254	32.0	710	89.8	104	21.5	24	18.3
302	36.4	697	87.1	165	26.2	104	23.3
375	43.6	688	84.4	245	32.7	154	26.9
462	53.1	675	80.9	318	39.4	250	33.6
527	61.6	666	79.9	425	51.2	340	44.2
627	76.4	655	77.8	473	57.4	351	44.9
700	90.2	635	75.9	541	66.3	420	52.4
742	98.7	604	70.9	596	74.2	512	63.0
751	100.7	477	54.8	655	83.8	633	81.1
760	102.2	300	36.2	689	89.3	700	90.4
773	105.3	0.44% C		716	94.2	713	92.2
789	108.6	30	22.9	728	96.4	722	93.4
817	111.3	85	27.2	732	98.5	722	93.7
851	113.8	177	34.0	734	101.4	728	94.8
862	124.5	226	37.1	736	105.2	734	95.8
890	115.8	289	42.4	745	107.6	735	96.4
901	117.0	338	47.2	760	109.7	736	98.4
888	115.1	426	56.9	780	111.4	737	100.4
851	112.9	520	67.5	807	112.3	738	101.8
810	110.3	577	75.4	854	113.8	738	106.4
772	105.8	657	86.6	890	115.5	747	107.3
746	100.0	702	95.8	904	116.3	750	107.6
709	92.1	709	96.8	890	115.8	753	107.9
650	80.7	717	98.0	834	113.8	775	108.3
390	45.3	721	98.8	736	109.7	794	109.1
0.18% C		726	99.4	710	107.2	832	110.6
24	16.5	728	100.3	694	103.6	864	112.1
89	18.3	731	101.0	686	101.8	889	112.8
152	24.3	736	102.8	680	98.5	920	113.9
213	28.9	737	103.9	677	92.8	864	111.9
257	31.8	742	105.9	665	87.5	808	111.9
338	37.8	747	107.3	0.80% C		756	108.1
450	51.4	754	108.1	25	18.7	702	105.9
533	61.0	756	109.2	92	23.2	698	105.7
626	72.2	762	109.7	160	28.3	693	103.2
653	76.6	774	111.3	225	33.4	692	101.4
693	84.3	796	112.3	278	38.2	691	99.6
723	89.5	829	113.5	341	45.2	689	97.6
734	91.1	890	115.8	398	51.6	685	94.8
747	93.7	908	116.2	514	66.0	682	92.9
750	95.0	891	115.8	612	80.4	668	85.3
767	99.4	845	113.6	675	90.2	1.30% C	
777	101.7	813	112.8	683	91.0	81	23.9
799	104.3	762	110.9	721	98.8	117	28.2
809	105.4	753	110.1	732	101.3	260	37.5
823	106.5	746	109.4	738	104.8	365	48.5
832	106.7	728	109.2	741	111.9	477	61.3
835	107.0	721	107.3	754	113.0	538	68.5
843	108.0	710	106.9	764	114.4	606	78.2
866	108.7	707	106.5	797	115.0	634	82.4
890	109.2	673	99.2	841	116.7	660	85.8
918	110.0	670	96.9	880	118.5	700	92.0
891	109.4	662	92.5	913	119.5	710	93.6
862	108.2	651	87.2	870	112.8	719	94.3
839	107.3	651	85.6	818	115.8	722	95.3
818	106.5	628	83.6	748	113.5	727	96.8
797	105.0	518	68.1	704	111.4	728	97.0



## Fe-C.—(Continued)

Swedish iron +C.— (Cont'd)		Swedish iron +C.— (Cont'd)		Resistivity in magnetic field H (126)			
t	$\rho_t$	t	$\rho_t$	0.64% C; H = 80.1		1.02% C; H = 80.1	
1.30% C		1.50% C					
734	97.5	907	126.1	240	32.15	704	90.4
739	98.6	888	124.9	281	35.9	715	92.0
742	104.4	841	122.4	342	41.9	723	93.8
743	106.7	832	121.7	427	51.25	737	97.4
746	107.5	826	121.7	487	59.8	760	103.4
750	108.0	791	118.9	561	68.8	772	106.1
753	108.7	783	118.1	659	82.8	779	108.1
754	108.5	767	117.8	672	85.3	784	109.4
762	108.8	703	116.0	679	86.4	801	111.0
774	109.8	990*	112.9	686	87.8	819	112.3
801	110.8	689	110.8	711	91.7	822	113.6
851	113.1	689	109.5	735	96.1	828	114.1
876	114.3	688	106.7	748	99.6	838	115.0
918	116.8	686	103.4	762	102.8	848	116.0
891	116.5	685	101.1	770	104.9	859	116.6
864	115.5	682	97.7	789	108.0	872	118.0
849	113.0	680	95.8	810	110.8	872	118.0
812	111.8	673	93.9	826	112.7	858	116.6
752	108.8	645	88.2	846	114.3	831	115.3
728	107.8	558	74.5	873	115.4	821	114.4
719	107.2	360	49.3	867	115.2	815	113.7
700	107.2	* Probably should be 690. † Probably should be 122.4.		851	114.6	802	112.8
697	106.4			821	113.45	788	111.4
697	103.7			801	112.3	776	110.7
696	102.4			784	110.8	761	109.2
696	100.4	Soft welding iron; 0.05% C (161)		763	108.0	750	107.0
694	97.8			750	105.4	744	105.9
692	95.1			742	103.1	731	103.3
691	91.5			714	96.2	720	100.3
690	91.1	t		698	91.9	712	97.8
681	89.4			687	89.1	706	95.6
676	87.9	15	17.82	675	86.4	701	93.8
653	85.2	290	48.5	662	84.2	694	92.1
551	70.7	460	75.1	652	82.4	687	89.4
1.50% C		750	140.0	622	77.2	680	86.6
23	19.1	800	154	560	68.9	667	84.25
86	23.8	860	166.8	488	58.7	653	82.0
160	29.0	910	170.6	427	51.25	637	80.0
247	36.5	1060	178.2	343	42.1	553	68.2
338	46.2	H-scale of temp. (169); ca. 1% C		280	35.9	442	53.9
432	57.2			230	31.1	369	46.6
562	74.5			1.02% C; H = 80.1		278	37.5
606	81.2			13	19.0	222	33.5
653	89.6	+ 16.2		116	25.7	179	29.5
698	87.5			213	32.4	154	28.0
708	98.5	-172.7	7.19	251	35.5	133	26.4
712	100.2	-173.9	7.12	312	41.2	71	22.2
719	100.7	-172.2	7.18	375	46.9	1.30% C; H = 80.1	
723	101.1	-165.2	7.54	433	53.0	14	65.1
728	102.7	-154.8	8.07	479	59.0	67	68.5
735	104.7	-146.9	8.36	530	65.2	164	75.3
736	105.2	-111.0	10.53	612	75.9	223	80.3
737	108.7	-101.9	11.13	634	79.2	299	86.8
738	109.9	-95.8	11.49	645	80.6	348	91.2
739	111.6	-92.7	11.69	654	81.9	403	97.1
741	112.6	-40.8	14.74	663	83.3	452	103.0
746	113.8	-39.6	14.84	673	84.6	492	107.4
753	114.5	-36.0	15.08			511	109.5
816	120.9	+ 21.8	18.67				
877	112.4†	+ 22.1	18.71				

## Fe-C.—(Continued)

## Resistivity in magnetic field H.—(Continued)

t	$\rho$	t	$\rho$	t	$\rho$	t	$\rho$
1.30% C; H = 80.1		1.30% C; H = 80.1		0.18% C; H = 187		0.44% C; H = 187	
559	115.9	716	147.0	721	95.9	631	81.6
588	119.8	701	142.0	730	97.8	647	83.7
606	121.4	686	137.4	743	101.3	656	85.0
610	122.6	677	135.0	753	103.8	668	87.0
632	125.6	662	130.7	757	105.1	677	88.5
642	127.0	652	128.9	775	107.3	687	90.0
655	129.1	642	127.5	788	108.9	703	92.7
668	131.0	632	125.9	801	110.6	712	94.1
678	132.6	602	121.9	807	111.4	722	96.2
685	134.7	537	112.5	813	111.7	727	97.4
697	136.5	389	95.5	823	112.6	730	97.9
731	144.3	270	84.4	834	113.4	734	99.4
740	147.0	226	79.8	845	114.4	742	101.4
750	150.1	196	77.6	863	115.4	752	103.4
756	151.6	157	74.6	872	115.7	762	105.1
760	152.5	101	70.8	876	116.0	771	106.5
772	154.0	83	69.2	0.44% C; H = 187		780	108.0
794	157.4	0.18% C; H = 187		15	22.4	789	109.2
810	159.0	15	18.6	69	25.9	796	110.0
824	159.9	124	25.9	126	29.5	806	111.2
837	160.7	177	29.6	193	34.1	814	112.0
864	161.8	230	33.8	238	37.7	826	112.5
876	162.0	281	38.1	290	41.9	828	112.7
888	161.8	331	42.7	323	45.0	835	113.0
858	159.7	341	43.5	349	47.2	840	113.1
838	158.8	395	49.0	372	49.8	845	113.4
825	158.1	473	58.6	391	51.6	862	113.8
811	157.3	526	65.1	425	55.5	871	114.0
797	156.3	596	75.0	466	60.2	882	114.2
771	154.6	650	83.2	513	65.6	890	114.3
758	153.8	660	85.3	600	77.2	899	114.2
741	152.0	691	90.7	617	79.4	907	114.0
725	149.4					917	113.8

## Fe-C-x

## Carbon steels; composition of x, 1/100 %

Key	Cr	Cu	Mn	Ni	S	Si	P
1			2.5		0.4	0.6	1.2
2		3	4		2.4	12	1
3		3	1		2.2	11	1
4		3	7		2.1	13	1
5		3	8		2.1	13	1
6		4	10		2.1	13	1
7		3	7		2.4	11	1
8		3	9		2.0	13	1
9		3	8		2.1	12	1
10		3	10		2.2	12	1
11		3	12		1.9	13	1
12		3	13		1.9	14	1
13		3	12		1.4	15	1.8
14	3	5	13	6	2.2	4	1.2
15	3	6	12	6	1.4	11	1.0
16	4	6	18	5	1.8	13	1.0
17			6		1.5	1.5	3
18			12		4.2	21	1.2
19			12		2.5	6	0.5
20			19		2.5	5	1
21	5		23		1.4	23	1.6



## INTERNATIONAL CRITICAL TABLES

Fe-C-x.—(Continued)

Elec. Fe + additions (241)

C + x	0.019 + 1		0.11 + 2	
$\alpha_0^*$	5.51		5.25	
$t_Q$			900	950
$\Delta Q^\dagger$			0.088	0.410
$t$	$\rho_i$	$\Delta_c^\ddagger$	$\rho_i$	$\Delta_c^\ddagger$
25	10.949	0.535	12.093	0.452
100	15.466	0.747	16.872	0.607
150	20.990	1.708	20.436	0.634
200	24.529	2.318	23.395	1.480
250	28.190	3.295	27.480	1.835
300	32.827	3.662	31.710	2.256
350	38.196	3.540	37.350	2.113
400	44.300	2.806	42.916	2.184
450	51.010	2.930	49.330	2.112
500	57.844	3.050	55.671	2.609
550	64.800	2.320	62.717	2.608
600	72.853	2.931	69.905	2.820
650	81.274	2.808	78.572	2.608
680	86.522	5.002	83.928	2.116
690	88.110	7.074	85.690	2.468
700	89.820	7.562	87.382	4.018
710	91.890	7.570	89.144	7.046
720	93.968	7.441	90.976	7.684
730	98.850	5.491	93.160	7.820
740	101.53	4.89	95.630	7.390
750	103.73	4.64	98.800	6.200
760	105.800	4.03	101.470	5.430
770	107.270	3.78	103.730	4.930
780	108.120	4.03	105.770	4.87
790	108.850	3.91	107.110	4.79
800	109.831	3.54	108.380	4.52
850	113.492	2.56	112.960	3.46
860			113.810	3.31
870			114.660	3.16
880	115.687	1.71	115.570	2.76
890	116.178	1.706	116.420	2.18
900	116.665	1.710	117.050	1.90
910	117.273	1.347		
920	117.519	1.464	118.400	1.33
930	117.884	1.466		
940	118.249	1.343		
950	118.620	1.215	119.800	0.70
980	119.716	0.975	121.000	0.63
1000	120.447	0.609	121.560	0.56
1020	121.183	0.606	122.400	0.22
1050	122.153	0.247	124.030	
1080	123.008	0.123		
1100	123.620			

C + x	0.17 + 3		0.35 + 4	
$\alpha_0^*$	4.98		4.51	
$t_Q$	900	950	900	950
$\Delta Q^\dagger$	0.101	0.606	0.551	1.429
$t$	$\rho_i$	$\Delta_c^\ddagger$	$\rho_i$	$\Delta_c^\ddagger$
25	12.851	0.213	14.636	0.175
100	17.597	0.447	19.465	0.470
150	20.601	1.421	22.783	0.783
200	24.012	1.420	25.986	1.780
250	27.776	1.564	30.045	1.852
300	32.181	1.562	34.460	1.993

\* 25 to 100°C.

†  $\Delta Q = \rho_Q' - \rho_Q''$ ;  $\rho_Q'$  ( $\rho_Q''$ ) =  $\rho$  for specimen quenched at  $t_Q$  (at 850°).‡  $\Delta_c = \rho_{ic} - \rho_{ih}$ ;  $\rho_{ih}$  ( $\rho_{ic}$ ) =  $\rho_i$  for heating (cooling).

Elec. Fe + additions.—(Continued)

C + x	0.17 + 3		0.35 + 4	
$\alpha_0^*$	4.98		4.51	
$t_Q$	900	950	900	950
$\Delta Q^\dagger$	0.101	0.606	0.551	1.429
$t$	$\rho_i$	$\Delta_c^\ddagger$	$\rho_i$	$\Delta_c^\ddagger$
350	37.083	2.273	40.511	1.495
400	43.334	2.122	46.064	2.136
450	49.160	2.555	51.831	2.279
500	55.554	2.556	58.381	2.279
550	62.657	2.130	64.930	2.138
600	70.260	2.200	73.190	0.513
650	78.286	2.554	81.380	0.851
680	83.544	2.626	86.504	0.784
690	85.250	2.696	88.284	1.068
700	86.882	3.128	90.064	2.208
710	88.730	5.751	91.844	7.548
720	90.434	6.466	93.480	10.610
730	92.350	6.965	95.402	10.608
740	94.840	6.750	97.540	10.390
750	98.745	5.045	102.740	7.260
760	101.440	4.480	107.510	4.270
770	103.720	4.120	109.640	3.190
780	105.850	3.910	111.280	2.700
790	107.270	3.480	112.630	2.070
800	108.550	3.120	113.350	1.840
850	112.950	2.700	116.190	0.930
860	114.310	1.840		
870	115.650	0.996		
880	116.510	0.560	117.540	0.780
890	117.000	0.427		
900	117.356	0.494	118.250	0.720
920	118.067	0.353	118.970	0.640
950	119.210	0.280	120.180	0.500
980	120.270	0.140	121.110	0.420
1000	120.830	0.150	121.820	0.140
1020	121.550	0.070	122.530	0.070
1050	122.610		123.600	

C + x	0.45 + 5		0.54 + 6	
$\alpha_0^*$	4.24		4.09	
$t_Q$	900	950	900	950
$\Delta Q^\dagger$	0.830	1.792	0.239	1.262
$t$	$\rho_i$	$\Delta_c^\ddagger$	$\rho_i$	$\Delta_c^\ddagger$
25	15.333	0.147	16.506	0.151
100	20.225	0.163	21.421	0.521
150	23.301	0.852	25.240	0.431
200	27.563	0.710	28.110	1.433
250	31.683	0.997	31.910	1.792
300	36.087	1.777	36.283	2.295
350	41.354	1.838	42.450	1.434
400	47.100	1.757	48.330	1.291
450	53.142	1.700	53.934	0.562
500	59.177	2.485	60.592	0.932
550	65.924	1.776	66.686	+2.297
600	73.313	1.847	77.720	-1.569
650	81.696	1.422	82.680	+0.572
680	86.740	1.420	87.626	1.004
690	88.310	1.554	89.562	0.648
700	89.937	1.774	91.212	0.716
710	91.500	9.020	92.860	4.302
720	93.275	13.285	95.082	12.838
730	95.190	13.500	96.802	13.838
740	97.325	13.285	98.452	14.198
750	104.290	8.090	103.110	10.830



## Fe-C-x.—(Continued)

## Elec. Fe + additions.—(Continued)

C + x	0.45 + 5		0.54 + 6	
$\alpha_0^*$	4.24		4.09	
$t_Q$	900	950	900	950
$\Delta_Q^\dagger$	0.830	1.792	0.239	1.262
$t$	$\rho_t$	$\Delta_c^\ddagger$	$\rho_t$	$\Delta_c^\ddagger$
760	109.540	4.120	110.570	4.090
770	111.460	2.980	112.940	2.290
780	112.960	1.840	114.150	1.440
790	113.820	1.260	114.940	1.080
800	114.230	1.210	115.380	1.070
850	116.360	1.070	117.450	1.010
880	117.430	1.280	118.460	0.930
900	118.140	1.280	119.110	1.000
920	118.850	1.210	119.890	0.860
950	119.920	0.990	121.040	0.740
980	120.980	0.780	122.040	0.500
1000	121.690	0.640	122.760	0.360
1020	122.400	0.500	123.470	0.220
1050	123.46		124.56	

C + x	0.63 + 7		0.81 + 8	
$\alpha_0^*$	4.20		3.81	
$t_Q$	900	950	900	950
$\Delta_Q^\dagger$	0.309	1.806	3.982	5.014
$t$	$\rho_t$	$\Delta_c^\ddagger$	$\rho_t$	$\Delta_c^\ddagger$
25	16.727	-0.169	17.790	0.128
100	21.617	+0.500	22.925	0.051
150	25.296	0.554	26.227	0.939
200	29.029	0.761	29.840	1.228
250	33.175	0.347	33.741	1.734
300	37.807	0.206	38.221	1.879
350	43.474	0.138	43.567	1.300
400	49.420	0.137	49.637	1.155
450	55.640	0.205	55.271	1.445
500	62.273	0.208	61.270	2.310
550	69.050	0.273	68.060	2.457
600	76.511	0.275	75.864	1.300
650	84.322	0.342	83.740	0.940
680	89.300	0.344	88.724	1.010
690	90.890	0.412	90.530	1.157
700	92.614	0.486	92.050	1.300
710	94.136	7.534	93.855	7.875
720	95.794	14.656	95.370	17.990
730	97.525	15.685	97.032	17.488
740	99.460	15.620	99.057	15.823
750	108.160	8.090	107.290	8.240
760	115.570	1.170	114.810	1.070
770	116.940	0.210	115.530	0.860
780	117.360	0.200	115.750	1.080
790	117.770	0.210		
800	118.190	0.140	116.470	1.080
850	120.260	0.140	118.340	1.230
880	121.440	0.070	119.430	1.230
900	122.130	0.090	120.150	1.160
920	122.410	0.340	121.020	1.010
950	123.440	0.280	122.110	0.930
980	124.410	0.210	123.410	0.350
1000	125.100	0.140	124.120	0.220
1020	125.790	0.140	124.850	0.360
1050	126.760		125.930	

\*25 to 100°C.

 $\dagger \Delta_Q = \rho_Q' - \rho_Q''$ ;  $\rho_Q'$  ( $\rho_Q''$ ) =  $\rho$  for specimen quenched at  $t_Q$  (at 850°). $\ddagger \Delta_c = \rho_w - \rho_h$ ;  $\rho_h$  ( $\rho_w$ ) =  $\rho_t$  for heating (cooling.)

## Elec. Fe + additions.—(Continued)

C + x	0.89 + 9		1.00 + 10	
$\alpha_0^*$	3.68		3.99	
$t_Q$	900	950	900	950
$\Delta_Q^\dagger$	1.596	2.393	1.797	2.877
$t$	$\rho_t$	$\Delta_c^\ddagger$	$\rho_t$	$\Delta_c^\ddagger$
25	19.309	0.298	19.091	-0.377
100	24.628	0.414	24.537	+0.043
150	28.835	0.000	27.898	0.919
200	32.555	0.429	31.853	0.565
250	36.704	0.573	36.162	0.495
300	41.355	0.788	40.965	0.212
350	47.080	0.714	46.474	0.353
400	52.874	0.572	52.125	0.713
450	58.670	0.859	57.916	0.494
500	65.110	0.714	64.131	0.989
550	71.548	0.715	70.981	0.919
600	78.776	1.000	78.043	0.497
650	86.574	0.858	85.954	0.566
680	90.940	1.500	90.756	0.636
690	92.440	1.502	92.312	0.916
700	94.017	1.429	93.864	0.778
710	95.660	12.160	95.632	3.957
720	97.450	19.240	97.466	14.834
730	99.310	18.030	99.305	17.165
740	101.610	16.160	101.000	16.380
750	106.250	11.950	109.190	8.690
760	117.050	1.580	116.530	1.770
770	117.550	1.436	116.890	1.837
780	117.986	1.424	117.313	1.837
800	118.840	1.290	118.230	1.700
850	120.986	1.224	120.350	1.347
880	122.277	0.573	121.764	1.126
900	123.060	0.720	122.470	1.130
920	123.780	0.714	123.250	0.987
950	124.780	0.720	124.450	0.632
980	125.856	0.714	125.365	0.421
1000	126.500	0.710	126.000	0.285
1020	127.210	0.720	126.774	0.146
1050	128.356		127.830	

C + x	1.22 + 11		1.43 + 12	
$\alpha_0^*$	3.81		3.35	
$t_Q$	900	950	900	950
$\Delta_Q^\dagger$	2.615	4.212	2.416	4.046
$t$	$\rho_t$	$\Delta_c^\ddagger$	$\rho_t$	$\Delta_c^\ddagger$
25	21.011	0.489	22.888	-0.129
100	26.356	1.994	28.611	-0.126
150	32.053	1.069	32.077	-0.278
200	36.470	1.850	35.547	+0.070
250	40.600	2.850	39.714	0.276
300	45.444	2.849	44.295	0.695
350	50.574	2.849	49.433	0.972
400	55.701	2.707	55.404	+0.696
450	61.400	2.564	62.170	-0.030
500	67.668	2.065	68.041	+0.556
550	74.078	2.068	74.638	0.208
600	81.560	1.922	81.790	0.136
650	89.750	1.424	89.564	0.208
680	94.310	1.636	94.284	0.836
690	95.878	1.850	95.812	0.832
700	97.300	2.280	97.410	0.832
710	98.890	15.790	98.943	0.479
720	100.435	17.305	100.530	9.860
730	102.214	16.240	102.614	14.859



**Fe-C-x.—(Continued)**  
Elec. Fe + additions.—(Continued)

C + x	1.22 + 11		1.43 + 12	
$\alpha_0^*$	3.81		3.35	
$t_Q$	900	950	900	950
$\Delta Q^\dagger$	2.615	4.212	2.416	4.046
$t$	$\rho_t$	$\Delta_c^\ddagger$	$\rho_t$	$\Delta_c^\ddagger$
740	104.138	14.818	104.280	13.750
750	113.968	5.412	109.620	8.893
760	118.170	1.640	117.888	1.045
770	118.454	1.713	118.235	1.115
780	118.880	1.710	118.724	1.106
790	119.380	1.709	119.350	0.900
800	119.876	1.640	119.900	0.700
840	121.730	0.853		
850	122.156	1.284	122.056	0.484
860	122.510	1.430		
870	122.730	1.570		
880	123.154	1.496	123.377	0.273
900	123.869	1.351	124.140	0.345
920	124.580	1.417	124.970	0.210
950	125.579	1.281	126.220	0.070
960			126.500	0.064
970			126.847	0.071
980	126.786	0.858	127.120	0.140
1000	127.570	0.710	127.680	0.140
1020	128.427	0.500	128.235	0.138
1050	129.635		129.070	

C + x	1.54 + 13		C + x	1.54 + 13	
$\alpha_0^*$	3.43		$\alpha_0^*$	3.43	
$t_Q$	900	950	$t_Q$	900	950
$\Delta Q^\dagger$	4.406	5.319	$\Delta Q^\dagger$	4.406	5.319
$t$	$\rho_t$	$\Delta_c^\ddagger$	$t$	$\rho_t$	$\Delta_c^\ddagger$
25	21.550	-0.073	760	119.860	2.366
100	27.120	-0.146	770	120.220	2.434
150	30.664	+0.286	780	120.575	2.505
200	34.318	0.932	800	121.578	2.582
250	38.043	2.149	850	123.946	2.854
300	43.058	1.719	880	125.380	2.861
350	48.649	1.931	900	126.450	2.800
400	54.449	1.647	920	127.670	2.724
450	60.540	1.790	950	129.250	2.215
500	66.700	1.720	960	129.750	2.074
550	73.650	1.720	970	130.173	2.003
600	81.171	1.937	980	130.680	1.860
650	88.982	2.004	990	131.181	1.719
680	93.710	2.364	1000	131.609	1.791
690	95.145	2.791	1010	131.900	1.715
700	96.646	4.014	1020	132.185	1.645
710	98.225	16.407	1030	132.540	1.480
720	99.942	20.350	1040	132.975	1.125
730	101.735	19.129	1050	133.050	1.250
740	103.740	17.624	1080	133.900	0.600
750	107.107	14.687	1100	134.600	

\* 25 to 100°C.

†  $\Delta Q = \rho_Q' - \rho_Q''$ ;  $\rho_Q' (\rho_Q'')$  =  $\rho$  for specimen quenched at  $t_Q$  (at 850°).‡  $\Delta_c = \rho_c - \rho_{cH}$ ;  $\rho_{cH} (\rho_c)$  =  $\rho_t$  for heating (cooling).**Fe-C-x.—(Cont'd)**

C (262)	$x^*$	$\rho_{20}$
0.05	14	12.09
0.12	14	12.80
0.22	14	13.94
0.43	14	14.78
0.50	14	15.66
0.58	15	16.44
0.63	15	16.06
0.78	15	17.11
0.86	15	17.79
0.97	15	18.26
1.09	16	18.62
1.33	16	18.84
1.40	16	18.98
1.52	16	19.42
1.49	16	19.79
1.65	16	20.63
1.64	16	19.87

\* See p. 175.

C (93)	$x$	$\rho_{18}$	$\alpha_0$
0.105	17	10.11	5.4
0.57	18	16.4	3.5
0.99	19	16.35	3.9
1.50	20	18.15	3.3

Eutectoid (206)

0.85 | 21 | 20.25\*

\* Air-cooled; furnace-cooled,  $\rho = 19.3$  to 19.6.Effect of drawing to wire  
(13, 14, 68)

C	$\rho_A$	$\rho_D$	Lit.
0.028*	10.6	10.47	(13, 14)
0.35†	22.0	21.6	(68)
0.79†	21.7	20.9	(68)

\* Pure commercial iron, 0.028C, 0.07Si, 0.009(S + P);  $t = 18^\circ$ ,  $\alpha_D = 6$  for 0 to 150°C.† Initial diameter = 6 mm, drawn to 1.5 mm. For unannealed;  $\rho_0 = 25.2$ ,  $\rho_D = 20.8$  if C = 0.35; and  $\rho_0 = 27.0$ ,  $\rho_D = 21.0$  if C = 0.70.**Fe-Co,  $T_{p_{900}}$  (46)**

Co	$\rho$
0.32	14.4
0.58	15.5
1.035	12.5
2.0	13.5
3.0	14.3*
4.055	15.4
6.02	18.3

Electrolytic Fe; F (300)

0	$\rho$
34.6†	9.9
	9.4
$A_{900}$	
0	9.85
34.6†	9.94
$A_{1100}$	
34.6†	9.85

\*  $\rho_{Hm} = 14.7$ ; for  $T_{p_{1000}}$ ,  $\rho = 11.7$ .  
† FeCo.**Fe-Co.—(Continued)**

Co	$\rho$
(200)	
0	12.0
10	16.3
20	20.0
30	20.0
100	9.7

**Fe-Co-x\* (124)**

Co	$\rho$
0	16.62
5	21.94
10	24.76
15	25.26
20	23.53
30	16.45
40	13.48
50	11.24
70	9.21
80	13.37
90	16.37
100	8.59

\* Impurities in Fe = 0.31Mn, 0.288Cu, 0.11Si, 0.030P, 0.026S, 0.09C; in Co = 1.4Fe, 1.1Ni, 0.14Si, 0.24C.

**Fe-Co-Mn-Si-C (12, 13)** $t = 18^\circ\text{C}$ ;  $t_A = 1000^\circ\text{C}$ 

Co	Mn	Si	C	$\rho_A$	$\rho_0$
1.8	1.0	0.64	0.25	23.2	27.3
7.0	0.8	0.80	0.52	30.7	33.6

Fe-Cr; at 18°C,  $\delta_2 = 10$ ,  $\delta_3 = 11.5$ ,  $\delta_5 = 14$  (9) $T_{p_{900}}$  (46)

Cr	$\rho$
3.27	26.7
6.00	37.5*
6.68	39.7
8.83	46.8
13.01	46.0
16.57	50.0

\*  $\rho_{Hm} = 52.5$ ; for  $T_{p_{1000}}$ ,  $\rho = 64.4$ .

Cr	$\rho_{20}$	$\alpha_{20}$
(135)		
0	9.96	4.80
9.1	41.1	2.33
13.0	41.2	2.33
16.7	52.1	2.47
20.0	43.7	2.30

(200)

0	$\rho$
10	54.0
20	60.0
22	60
24	57.8
30	55.9

**Cimet (65)**

Cr	$\rho_{17}$	$\rho_{1100}$
25	17.3	45
25	43.9	114.2

**Fe-Cr-Al-C; v. Fe-Al-Cr-C**



## Fe-Cr-Al-Cu (46)

Cr	Al	Cu	$\rho_{Hm}$
8.7	1	1	35.6

## Fe-Cr-C (14)

Cr	C	$\rho_A$
2.00	0.90	21.93
9.50	1.09	34.63

Chrome steel. (219); cf. (27)

Cr	C	$\rho_Q^*$	$\rho_O$
1.20	0.06	18.0	16.3
2.66	0.28	31.0	29.7
4.50	0.21	35.0	33.2
7.84	0.07	53.0	50.9
10.14	0.15	50.8	49.7
13.36	0.17	66.6	60.0
14.52	0.38	69.7	62.9
16.71	0.15	68.1	64.7
22.06	0.21	57.7	56.0
25.31	0.24	60.2	57.5
31.75	0.46	66.3	63.7

\*  $t_Q = 980^\circ\text{C}$ ;  $t = 12$  to  $17^\circ\text{C}$ .

Cr	C	$\rho_Q^*$	$\rho_O$
0.62	0.86	43.5	23.1
0.99	0.97	50.2	25.8
2.14	0.89	54.0	27.8
4.57	0.79	56.3	29.4
7.28	0.84	62.2	39.1
9.38	0.75	66.5	56.4
13.94	0.70	72.5	65.4
14.54	0.74	73.1	66.2
18.65	0.90	38.3	60.7
26.54	0.82	68.4	67.1
32.46	0.92	67.5	66.3
36.34	0.83	68.5	65.1
40.03	0.80	73.5	71.5

\*  $t_Q = 980^\circ\text{C}$ ;  $t = 15$  to  $20^\circ\text{C}$ .

0.6% C; cylinders 20 cm long, 5 mm diam. (179)

Cr	$\rho_A^*$	$\rho_Q^\dagger$
0	20.7	20.7
0.5	22.0	22.4
1	21.9	22.8
2	21.1	22.9
3	25.6	35.5
5	32.3	44.8
10	45.4	51.3
15	46.5	60.2
20	51.6	63.7

\*  $t_A = 900^\circ\text{C}$ .  $\dagger t_Q = 1100^\circ\text{C}$ .

18°C (12, 13)

Cr	C	$\rho_A^*$	$\rho_O$
2.0	0.90	24.2	
3.25	0.43	24.9	35.55
9.50	1.09	38.2	43.45

\*  $t_A = 1000^\circ\text{C}$ ;  $t = 18^\circ\text{C}$ .

0°C (118, 176)

Cr	C	$\rho_O$	$\rho_A^*$	$\rho_Q$
0.29	0.16	22.34	19.17	19.05
1.18	0.27	33.51	33.05	57.06
5.19	0.77	20.12	22.34	40.62
9.18	0.71	23.15	24.01	28.43
1.12	0.54	19.78	17.15	32.06

## Fe-Cr-C—(Cont'd)

Cr	C	$\rho_O$	$\rho_A^*$	$\rho_Q$
2.19	0.20	27.04	20.43	29.07
4.17†	0.08	33.47	25.70	29.56

\* Straining the annealed wire decreases  $\rho$  by about 4 %.† 13% Cr.  $\rho_O = 52$ ,  $\alpha_O = 1$ , 20 to  $100^\circ\text{C}$  (148).

## Fe-Cr-Cu-Al; v. Fe-Cr-Al-Cu

Cr	Cu	C	$\rho_A^*$	$\rho_O$
5.75	1.80	0.85	31.2†	42.7

\*  $t_A = 1000^\circ\text{C}$ .  $\dagger t$  not stated; at  $18^\circ\text{C}$ ,  $\rho_A = 29.2$  (13).

## Fe-Cr-Mn-C; v. Fe-Mn-Cr-C (Si)

Cr	Mn	Ni	Mo	C	$\rho_{Tp}^*$	$\rho_{Hm}$
10	10	10	6	1	78.0	63.8

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-Mn-Si-(V) (46)

Cr	Mn	Si	V	$\rho_{Tp}^*$	$\rho_{Hm}$
20	3	1		67.1	65.3
21.4	3	1	1	82.0	76.8

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-Mn-Si-C; v. Fe-Cr-Si-C-(Mn, P, S)

Cr	Mo	Mn	Si	$\rho_{Tp}^*$	$\rho_{Hm}$
10	5			50.0	47.9
10	10			49.4	48.1
5	4	3	1	54.0	48.6

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-Mo-W-(Si, V, C); v. Fe-Cr-W-(C, Mo, Si, V)

Cr	Ni	Si	V	$\rho_{Tp}^*$	$\rho_{Hm}$
10	5			50.0	47.9
10	10			49.4	48.1
5	4	3	1	54.0	48.6

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-Ni; v. Fe-Ni-Cr

Cr	Ni	Si	V	$\rho_{Tp}^*$	$\rho_{Hm}$
20	10	1	0.3	75.7	76.0

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-Ni-Si; v. Fe-Ni-Cr-Si

Cr	Si	$\rho_{Tp}^*$	$\rho_{Hm}$
4.0	0.84	46.9	41.6
5.0	0.84	39.6	39.6
5.0	1.4	57.0	47.7
6.0	0.4	42.4	35.0
6.0	0.84	49.1	42.4
6.0	1.3	59.5	47.4
8.0	1.0	61.2	53.2
10.0	2.0	59.8	75.0
10.0	3.0	84.0	87.5
10.0	5.0		103.0
13.0	1.8	85.6	75.8
15.0	2.0		92.6
17.0	1.5	76.0	72.8

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-Ni-Si-V (46)

Cr	Ni	Si	V	$\rho_{Tp}^*$	$\rho_{Hm}$
20	10	1	0.3	75.7	76.0

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-Si (46)

Cr	Si	$\rho_{Tp}^*$	$\rho_{Hm}$
4.0	0.84	46.9	41.6
5.0	0.84	39.6	39.6
5.0	1.4	57.0	47.7
6.0	0.4	42.4	35.0
6.0	0.84	49.1	42.4
6.0	1.3	59.5	47.4
8.0	1.0	61.2	53.2
10.0	2.0	59.8	75.0
10.0	3.0	84.0	87.5
10.0	5.0		103.0
13.0	1.8	85.6	75.8
15.0	2.0		92.6
17.0	1.5	76.0	72.8

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-Si-C-(Mn, P, S)

Steels;  $t_A = 1000^\circ\text{C}$ ,  $t_Q = 940^\circ\text{C}$ ,  $t_{Tp} = 1100^\circ\text{C}$   
 $t = 18^\circ\text{C}$  (12, 13)

Cr	Si	C	$\rho_A$	$\rho_O$
2.0	1.00	0.76	31.8	36.4
2.0	1.80	0.86	44.1	51.0
3.5	2.25	0.54	50.6	54.8

 $t = 15^\circ\text{C}$  (165, 166); v. also Table 4

Cr	Si	Mn	C	$\rho_{Tp}$	$\rho_O$
2.5	0.27	0.23	0.50	40.9	19.5
2.8	0.27	0.21	0.82	66.7	21.5
2.4	0.36	0.21	1.07	72	24

 $t \geq 800^\circ\text{C}$  (25)

Cr	Si	Mn	C	$\rho_{800}$	$D$
2.19	0.27	0.23	0.50	99.0	3.1
2.83	0.27	0.21	0.82	81.2	1.7
3.44	0.36	0.21	1.07	87.7	2.55

 $t = 0^\circ\text{C}$ ; v. also Table 4 (128); ( $\frac{1}{1000}\%$ ) 42P, 20S

Cr	Si	Mn	C	$\rho_A$	$\rho_Q$
620*	220	393	532	19.42	27.08
1195*	134	-28	687	18.49	30.35

\*  $\rho_F$  for 620Cr = 20.16, for 1195Cr = 17.91. $t = 25^\circ\text{C}$ ; before (after) decarbonization ( $\frac{1}{1000}\%$ ); 1400Cr, 450Si, 380Mn, 7P (50)

S	C	$\rho_A$	$\rho_Q$	
11	1050	24.20	49.60	Before
3*	350	26.57	27.25	After

## Fe-Cr-Si-Ni-C (134); 22.06Cr, 1.67Si, 0.87Ni, 0.18C

$t$	$\rho_t$	$t$	$\rho_t$	$t$	$\rho_t$
20	97.5	500	119.5	800	130.6
300	110.1	600	125.7	900	132.4
400	114.6	700	128.4	1000	134.2

## Fe-Cr-Si-(Ti, V, C) (46); Cr10, Si2

Ti	V	C	$\rho_{Tp}^*$	$\rho_{Hm}$
2			86.0	79.5
	0.3	0.6	77.4	59.2
	1.0	0.3	84.9	83.4

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-V-(C) (46)

Cr	V	C	$\rho_{Tp}^*$	$\rho_{Hm}$
5.0	0.3		35.7	35.0
5.0	0.5		34.4	34.4
5.0	1.0		26.8	36.1
10.0	0.3		45.7	49.2
10.0	0.5			51.3
10.0	1.0		74.8	45.9
10.0	0.3	0.65	55.0	49.9

\*  $t_{Tp} = 1000^\circ\text{C}$ .

## Fe-Cr-W-(C, Mo, Si, V†) (46)

Cr	W	Mo	Si	C	$\rho_{Tp}^*$	$\rho_{Hm}$
2	10				28.3	28.0
3	10				30.5	30.0
10	2				51.5	51.4
10	10				57.8	60.7
5	2			0.6	57.8	47.4
5	5			0.6	57.8	56.8
10	2			0.6	55.7	53.6
7	3	2			40.9	43.9
10	2	2			49.7	50.9
10	2	2		0.6		61.6



## Fe-Cr-W-(C, Mo, Si, V).—(Continued)

Cr	W	Mo	Si	C	$\rho_{Tp}^*$	$\rho_{Hm}$
7.23	9		3		87.9	89.5
10	2		2			72.8
10	5		3		87.9	92.2
10	2	2	2		83.8†	77.4†
6	18			0.69	48.0†	50.3†
10	2				49.8†	53.3†
10	2			0.6	60.4†	60.0†

\*  $t_{Tp} = 1000^\circ\text{C}$ .

† Alloys so marked contain 0.3 % V.

Steel:  $t = 18^\circ\text{C}$ ;  $t_A = 1000^\circ\text{C}$  (12, 13)

Cr	W	C	$\rho_A$	$\rho_O$
0.75	2.0	0.25	17.9	22.5

Fe-Cu; v. also Cu-Fe;  $\delta_1 = -0.18$  (146); both electrolytic (45, 46)

Cu	$\rho$	Cu	$\rho$	Cu	$\rho$
$Tp_{900}$		Hm		$A_{1000}$	
0.089	12.2	0.5	14.0	0.5	12.2
0.202	12.0	1.0	11.4	1.0	11.8
0.422	13.6	1.0	16.4	1.0	13.2
0.804	13.6	2.0	15.6	2.0	11.2
1.006	14.7	3.0	15.5	2.5	9.5
1.51	17.0	3.5	14.7	3.0	12.4
2.05	13.4	4.0	13.6	3.5	8.6
3.99	12.7	5.0	15.7	4.0	12.5
5.07	12.5	90.0	5.09	5.0	12.8
6.16	12.7	90	5.53		
7.05	15.8	98	4.46		
94.34	3.92				

## Fe-Cu-(Al, As, Mn, Si) (46)

Cu	Al	As	Si	$\rho_A^*$	$\rho_{Hm}$
1.0	0.5			14.5	18.8
2.0	0.5				18.5
3.0	1.0			8.0	21.8
5.0	1.0			18.1	20.0
5.0	1.0			17.6	19.9
6.0	1.0			17.6	19.8
3.0		1.0		15.1	22.1
5.0		1.0		19.6	20.5
0.5			0.25	13.1	17.0
0.5			0.5	21.8	22.0
1.0			0.5	18.3	21.7
1.0			1.0	19.2	22.9
2.0			1.0	22.2	24.8
3.0			0.5	8.1	20.2
3.0			1.0	17.8	25.3
5.0			1.0	22.6	25.3
5			2	26.5	
6			1	22.8	
6.67			6.67	15.7	23.4

\*  $t_A = 1000^\circ\text{C}$ .Steels (12); cf. (13);  $18^\circ\text{C}$ 

Cu	Al	Mn	C	$\rho_A^*$	$\rho_O$	$\rho_D^\dagger$	$\alpha_0^\dagger$
1.59		0.36	0.68	14.9	19.8	13.92	4.18
2.50		0.32	0.59	14.4	19.0	13.55	4.57
2.87		0.14	0.17	17.4	21.5	16.15	3.66
3.75	1.0	0.16	0.04	21.0	24.9	20.77	2.80

\*  $t_A = 1000^\circ\text{C}$ . † Wire; annealed.Fe-Cu-Ni-Mn-C; v.  
Fe-Ni-Cu-C-(Mn)Fe-Cu-W-Cr-C; v.  
Fe-W-Cu-Cr-CFe-Mn;  $\delta_1 = 6.27$  (146); at  $18^\circ\text{C}$ ,  $\delta_2 = 16$ ,  $\delta_3 = 18$ ,  $\delta_4 = 24.5$  (9).

S = 0 to 0.028; C = 0 to 0.003 (305)

Mn	$\rho$
$A_{950, \text{vac}}$ (305)	
0.036	10.19
0.047	10.4
0.074	10.7
0.16	10.81*
0.16	11.04*
0.32	11.55*
0.29	12.24
0.54	13.42
0.59	15.04
$A_{1000}$ (46)	
1.0	18.4
2.0	24.8
3.0	28.4

## Fe-Mn.—(Cont'd)

Mn	$\rho$
$A_{1000}$ (46)	
3.5	30.6
6.0	40.0
8.0	53.0
10.0	55.8
$Tp_{900}$ (46)	
0.505	16.1
4.514	30.1
10.419	55.3
$Hm$ (46)	
3.5	30.2
6.0	40.8
8.0	49.1
10.0	54.8
Drawn and annealed (135)	
9.1	46.8
13.04	58
16.67	61

\* Ass.

Mn (76)	$\rho_0$	$\Delta_{100}$
12	67.148	1.27

## Fe-Mn-C (12, 13, 14)

For Hadfield's Mn-steel, v. Fe-Mn-Si-C-(P, S)

Mn	C	$\rho_A^*$	$\rho$	$\rho_O$
0.50	0.20	14.46	13.09	14.96
1.00	0.24	23.57	21.34	24.94
2.25	0.41	29.18		31.86
3.50	0.08†	29.67		31.29
4.00	0.36	28.69	25.98	33.74
4.75	0.36	29.38		38.23
5.15	0.32	37.41		46.50
5.40	0.15	33.74	30.52	46.51
13.00	0.26	61.50	55.6	63.70
15.20	0.15	64.94	58.9	67.00

Mn	C	$\rho_A$	Mn	C	$\rho_A$
1.00	0.75	26.88	11.50	1.66	61.50
3.81	0.78	44.12	13.00	1.23	63.60
7.00	1.20	58.74	15.25	1.50	66.18
10.10	0.16†	63.72	18.50	1.54	69.0

\*  $18^\circ\text{C}$ . † 0.13 % Si. ‡ 0.63 % Si.

1/100 %

19–25°C

Mn	C	P	S	Si	$\rho$
Iron (52)					
0	8	13	0.8	2.4	12.54
tr.	2.8	0.4	0.5	7	10.35
1.8	16	4.9	1.1	1.5	10.80
2.7	17	7.4	2.2	7.7	11.92
3.6	3.0	6.5	1.6	14	11.00
6.4	15	3.6	2	13	13.82
6.8	15	13	2	15	13.80
7.4	16	12	2.7	10	13.10
10	5.8	1.4	tr.	1.2	10.82
18.0	5.0	1.3	1.1	2	11.40



## Fe-Mn-C.—(Continued)

1/100%					19-25°C
Mn	C	P	S	Si	$\rho$
Steel (52)					
14.7	161	1.5	1.8	9.2	18.95
19	5	5.4	5.9	3	11.01
21	19	2.5	4	3.4	12.69
22	21.5	5.1	11.3		12.53
22.2	140	1	2.0	8.2	21.29
25	10	4	2	5	13.90
28	28	2.7	3.4	4	13.18
37	19	9	5	1	13.27
37	25	4	3	1.8	13.31
38	16	8	4	0.9	12.87
40	7	8	17	1.3	13.18
41	14	11	5	0.9	13.80
41	25	10	4	3	14.49
41	27	2.4	1	0.1	13.25
42	28	2.2	4	0.8	13.07
45	15	1.1	3.3	tr.	12.73
45	31	10	4	2.6	14.57
46	14.4	9	8	tr.	14.73
48	16	9.1	4	1	13.86
48	18.8	9	8	tr.	14.62
48	23	2.4	1	2.3	13.67
49	23	2.4	tr	0.4	13.30
49	33	6.8	5	2	15.32
55	10	8	5	2.4	13.83
56	22	2.4	34	tr.	14.15
57	19.2	2.4	34	tr.	14.03
57	24	2.9	1	0.3	13.64
65	28	8.3	6	5	16.21
66	16	7.4	3.0	1.4	16.09
68	22	7.7	7	5	16.09
72	41	3.9	4.1	11	18.17
73	37	9	4	6	17.10
77	43	10	4	6.6	19.80
80	23	1.6	3.3	1.6	17.10
80	36	10	4	4.7	19.80
83	26	5.3	1	0.4	16.25
87	36	8	9	4	17.27
89	23	5.8	1	0.5	16.32
95	20	10	8	5	19.87
95	30	6.3	1	1	16.96
99	29	8.4	1	1	16.95
108	22	10	5	6	19.81
109	17	9	5	0.4	20.90
127	33	9	5	5	22.72
158	74	4.3	3.6	20	19.69

Fe-Mn-C-(P, S, Si); cf. Fe-Mn-P-(C, Si, S), Fe-Mn-Si-C-(P, S),  
Fe-Si-Mn-C-(S, P)

Steel: 0.114Mn, 0.06Si, 0.05P, 0.04S, 0.206C. Manganese: 1.90Al,  
0.46Si, 0.24Fe, 0.07C (178)

Mn	$\rho$	Mn	$\rho$	Mn	$\rho$
0.11	14.8	1.1	20.7	5.0	44.8
0.31	17.5	1.6	22.4	7.9	54.0
0.6	19.0	2.0	26.3	8.8	52.9
0.8	19.95	3.0	30.9	9.8	54.9

Si = 0.1 to 1.4, P = 0.01 to 0.03, S < 0.01; 0.1 to 0.2% C (27)

Mn	$\rho_{18}$	Mn	$\rho_{18}$	Mn	$\rho_{18}$
0.432	15.5	6.139	59.4	12.92	75.8
2.150	25.4	10.512	73.1	14.4	72.5

## Fe-Mn-C-(P, S, Si).—(Continued)

Si = 0.05 to 0.5, P = 0.01 to 0.024, S = 0.01 to 0.025; 0.8 to 0.9% C  
(27)

Mn	$\rho_{18}$	Mn	$\rho_{18}$	Mn	$\rho_{18}$
0.461	27.9	3.084	40.3	10.08	70.2
1.031	31.0	5.112	51.8	12.096	71.2
1.972	38.4	7.2	63.5		

Si = 0.053 to 0.128, P = 0.023 to 0.049, S = 0.007 to 0.032 (27)

Mn	C	$\rho_{18}$	Mn	C	$\rho_{18}$
0.05	0.15	11.6*	0.40	0.57	17.5
0.40	0.09	13.4	0.40	0.92	18.6
0.40	0.29	15.7			

\* Puddled iron.

Mn	Si	C	$\rho_{17}$ (12)
0	0.08	0.14	13.4
0.10	0.10	0.78	16.1
0.14	0.12	1.23	19.1
0.18	0.20	0.84	17.2
0.25	0.06	0.83	16.7
0.32	0.17	0.85	17.9
0.32	0.17	1.09	17.6

0°C (176)

Mn	Si	C	$\rho_A$	$\rho_Q$
0.14	tr.	0.39	11.34	12.66
0.30	0.056	0.49	13.26	14.47
0.42	0.086	0.43	13.71	15.43
0.64	0.031	0.37	16.18	19.11
0.74	0.044	0.48	16.93	21.80
1.36	0.167	0.47	20.44	28.80

0°C;  $t_0 = 850$  to  $1050^\circ\text{C}$ ; 0.017P, 0.030S (176); cf. (174)

Mn	Si	C	$\rho_A$	$\rho_Q$
0.42		0.035	10.58	11.4
0.44		0.11	11.39	11.88
0.44		0.22	12.06	13.16
0.42	0.085	0.43	13.51	15.44
0.50	0.051	0.66	14.50	18.55
0.34	0.092	0.72	15.84	20.38
0.31	0.145	0.79	16.07	23.93
0.24	0.124	0.92	16.13	24.30
0.30	0.089	1.02	16.19	29.02
0.34	0.110	1.08	17.55	30.07
0.27	0.040	1.17	18.43	32.80
0.40	0.104	1.30	18.57	38.88
0.23	0.113	1.43	18.07	38.50
0.30	0.080	1.54	17.99	37.95

Mn-steel (274)

$$10^{-10}\delta_{tr} \equiv (\rho_{tr} - \rho) \div \rho; 10^{-6}\delta_H \equiv (\rho_H - \rho) \div \rho$$

$\rho_{tr}$  = value of  $\rho$  when longitudinal traction is  $1 \text{ g cm}^{-2}$ ;  $\rho_H$  =  
value of  $\rho$  when longitudinal magnetizing field is 1 cgs unit

$\rho_{Dd}$	$\rho_A$	$\delta_{tr}$	$\delta_H$
74.84	72.91	+11.30	+0.03

Fe-Mn-Cr-C-(Si) (12, 13); 18°C

Mn	Cr	Si	C	$\rho_A^*$	$\rho_O$
2.60	9.22		1.36	63.7	69.4
3.00	5.00		1.15	47.8	68.3
3.09	8.92		1.30	36.6	50.6
17.50	3.50		0.88	68.8	79.3
4.25	2.00	1.50	1.32	52.1	68.6

Fe-Mn-Cr-Ni-Mo-C; v. Fe-Cr-Mn-Ni-Mo-C



## Fe-Mn-Cu-C (12, 13); 18°C

Mn	Cu	C	$\rho_A^*$	$\rho_O$
2.0	1.75	0.25	25.2	29.5
8.0	2.75	0.64	51.8	71.4

\*  $t_A = 1000^\circ\text{C}$ .

## Fe-Mn-Mo-Ni-Si (46)

Mn	Mo	Ni	Si	$\rho_{Td}^*$	$\rho_{Hm}$
12	6	2	0.8	67.1	68.5

\*  $t_{Td} = 1000^\circ\text{C}$ .

## Fe-Mn-Ni; v. Fe-Ni-Mn

## Fe-Mn-Ni-Cr-Mo-C; v. Fe-Cr-Mn-Ni-Mo-C

## Fe-Mn-P-(C, Si, S) wire (287); cf. Fe-Mn-C-(P, S, Si), Fe-Mn-Si-C-(P, S), Fe-Si-Mn-C-(S, P), Fe-C-(x)

Mn	P	Si	S	C	$\rho$
0.00	0.019	0.07	tr.	0.02	9.30
0.00	0.022	0.01	0.00	0.02	9.69
tr.	0.044	0.00	tr.	0.02	9.44
0.10	0.023	0.01	0.01	0.14	9.55
0.12	0.109	0.08	0.01	0.13	12.10
0.15	0.116	0.10	0.01	0.09	11.51
0.09	0.118	0.16	0.05	0.11	10.81
0.13	0.128	0.08	0.01	0.04	11.74
0.11	0.157	0.07	0.01	0.06	11.80
0.32	0.043	0.00	0.00	0.03	10.19
0.29	0.048	0.01	0.06	0.01	10.69
0.28	0.058	0.00	0.06	0.03	10.96
0.27	0.063	0.00	0.05	0.03	10.45
0.33	0.063	0.00	0.05	0.02	10.49
0.40	0.115	0.00	0.06	0.03	12.38
0.47	0.085	0.00	0.03	0.08	14.56
0.49	0.141	0.00	0.08	0.01	10.09
0.59	0.101	0.00	0.04	0.05	13.34
0.69	0.096	0.00	0.02	0.08	14.32
1.22	0.101	0.01	0.01	0.16	16.70
1.17	0.127	0.01	0.02	0.11	18.23

## Fe-Mn-Si-C-(P, S); cf. Fe-Mn-C-(P, S, Si), Fe-Mn-P-(C, Si, S), Fe-Si-Mn-C-(S, P), Fe-C-x

Square bars, 20 cm long, 1 cm side;  $t_A = 600^\circ\text{C}$  (165, 166)

Mn	Si	C	$\rho_A$	$\rho_{Td}$
0	0	0	9.5*	
0	0	6.68	45†	
0.13	0.05	0.06	10.0	
0.15	0.08	0.20	12.5	
0.24	0.05	0.49	14.0	
0.24	0.13	0.84	16.0	
0.21	0.11	1.21	18.0	
0.14	0.09	1.40	18.4	
0.13	0.08	1.61	19.0	
0.24	0.1	0.9	17.8	
0.83	0.2	1.2	24.5	
0.95	0.1	0.9	22.0	
1.8	0.9	1.2	40.0	
13	0.3	1	80.0†	

Fagersta steels (21); 0.026% P;  $t = 20^\circ\text{C}$ 

Mn	Si	C	$\rho_A$	$\rho_{Td}$
0.321	0.009	0.16	12.59	13.6
0.431	0.019	0.23	13.74	15.4
0.412	0.040	0.33	14.67	17.2
0.422	0.078	0.38	15.11	18.3
0.409	0.308	0.62	20.82	30.6
0.449	0.303	0.95	21.11	38.6

\* Ferrite, pure iron. † Cementite,  $\text{Fe}_3\text{C}$ . ‡ When magnetized,  $\rho_A = 66$ .

## Fe-Mn-Si-C-(P, S).—(Continued)

 $t_A = 1000^\circ\text{C}$ ,  $t = 18^\circ\text{C}$  (12); cf. (13)

Mn	Si	C	$\rho_A$	$\rho_O$
tr.	0.07	0.028	10.2*	10.5*
0.036	0.14	0.03	10.9†	11.1†
0.18	0.02	0.05	11.3‡	11.5‡
	0.08	0.14	13.0	13.4
0.10	0.10	0.78	14.6	16.1
0.25	0.06	0.83	15.2	16.7
0.18	0.20	0.84	16.1	17.2
0.32	0.17	0.85	16.4	17.9
0.32	0.17	1.09	16.2	17.6
0.14	0.12	1.23	17.6	19.1
0.58	0.49	0.58	20.7	23.1
0.68	0.49	1.00	23.3	25.2
0.62	0.46	1.25	23.6	26.6
10.08	0.63	0.16	61.1	65.5
2.00	4.25	0.40	68.4	73.8

\* P = 0.004, S = 0.005. † P = 0.065, S = 0.016. ‡ P = 0.013, S = 0.011.

 $t \leq 900^\circ\text{C}$  (208)

Mn	Si	C	$\rho_A$	$\alpha_{900}$
0.43	0.24	0.08		0.33
0.35	0.02	0.11		0.33
0.57	0.33	0.22		0.43
0.47	0.13	0.37		0.38
0.25	(?)	1.05		0.40

 $t \leq 800^\circ\text{C}$  (25)

Mn	Si	C	$\rho_{800}$	$D_{800}$
1.83	0.882	1.183	110.9	2.26
2.20	0.984	1.941	111.3	3.3

Gysinge steels,  $t = 15-18^\circ\text{C}$ ,  $t_{Td} = 800^\circ\text{C}$  (20, 21)

Mn	Si	P	S	C	$\rho_A$	$\rho_{Td}$
0.13	0.03	0.009	0.005	0.08	10.5	10.9
0.29	0.12	0.013	0.02	1.50	17.9	50.6
0.29	0.08	0.013	0.03	1.70	17.7	
0.35	0.65	0.015	0.02	0.45	23.9	29.0
0.44	0.86	0.014	0.02	0.55	27.6	34.4
0.41	0.28	0.014	0.015	0.90	20.2	36.9
0.44	0.30	0.014	0.01	1.20	20.9	42.1
0.54	0.26	0.014	0.015	1.35	21.6	44.4

 $t = 0^\circ\text{C}$ ; quenched in oil (50, 128)

Mn	Si	P	S	C	$\rho_A$	$\rho_Q$	$\rho_F$
0.016		0.005	0.018	1.184	15.88	36.47	
4.73	0.608	0.078	0.023	0.674	39.28	55.56	53.68
7.97	0.502	0.128	tr.	4.510	105.20*		
8.74	0.094	0.072	0.024	1.298	63.16	70.66	69.93
12.36	0.204	0.070	0.038	1.005			65.54
11.57	0.25	0.055	0.026	0.133	51.93	57.77†	
11.57	0.25	0.055	0.023	1.150	53.85	68.57	

\* Spiegeleisen.

† After decarbonization of the following specimen.

Hadfield's 12% Mn steel;  $\alpha_{15} = 1.27$  (63)

$t$	$\rho_t$	$t$	$\rho_t$	$t$	$\rho_t$	$t$	$\rho_t$
-197.1	55.414	-81.9	61.236	+1.0	67.222	89.9	75.294
-106.1	60.042	0	67.148	16.15	68.520		



**Fe-Mn-Si-C-(P, S).—(Continued)**

Effect of drawing to wire (84); cf. (85)

$\rho_D$  is after 7 drawings;  $t = 16$  to  $18^\circ\text{C}$ , BB = Bessemer Base steel; OH = Open Hearth steel; specimens a and b; HR = hot rolled; HRA = hot rolled and annealed; D = drawn; DA = drawn and annealed.

1/100%	Mn	Si	P	S	C
BB.....	48	0.6	8.0	5.6	7
OH <sub>a</sub> .....	47	26.2	6.8	3.6	55
OH <sub>b</sub> .....	38	11.3	1.6	1.9	78
Steel	BB	OH <sub>a</sub>	OH <sub>b</sub>		
$t_A$ .....	400	910	1000		
$\rho_A$ .....	12.2	11.85	11.96		
$\rho_{HR}$ .....	14.38	21.70	18.80		
$\rho_{HRA}$ .....	14.32	21.40	18.60		
$\rho_D$ .....	14.72	19.40	20.47		
$\rho_{DA}$ .....	14.60	19.50	20.46		

**Fe-Mn-Si-Cr-C-(P, S); v. Fe-C-x****Fe-Mn-Si-Cu-C-(P, S) (252); cf. Fe-C-x**1.0 to 5.1P, 1.4 to 4.4S;  $t_A = t_Q = 900^\circ\text{C}$ ; 1/100%

Mn	Si	Cu	C	$\rho_A$	$\rho_Q$	$\rho_F$
39	31	10	14	19.1	19.3	19.1
34	10	10	18	17.5	17.7	17.5
65	23	13	31	20.0	23.6	21.5
67	34	9	44	21.4	24.1	23.2
30	18	9	56	18.9	19.7	18.9
27	6	9	64	17.7	18.2	17.8
35	10	7	75	19.3	20.1	19.4
30	10	8	80	19.2	20.2	19.1
35	13	8	94	19.9	23.0	19.9
36	8	5	102	20.0	24.1	19.6
40	8	6	130	21.8	22.3	20.9
36	5	5	150	21.8	25.0	21.8

**Fe-Mn-Si-Cu-Ni-Cr-C-(P, S); v. Fe-C-x****Fe-Mn-W-C; 18°C (12, 13); cf. Fe-W-Mn-C**

Mn	W	C	$\rho_A^*$	$\rho_O$
2.25	3.25	0.40	27.7	37.1
3.25	10.00	1.52	31.3	45.4
10.20	2.11	1.08	65.8	71.3
11.10	2.85	1.34	68.4	74.5

\*  $t_A = 1000^\circ\text{C}$ .**Fe-Mo (46)**

Mo	$\rho_{TD}$	$\rho_{HM}$	Mo	$\rho_{TD}$	$\rho_{HM}$
5.12	27.8*		12.0	32.6†	36.6
9.84	29.9†		13.69	35.1†	

\*  $t_D = 900^\circ\text{C}$ . †  $t_D = 1000^\circ\text{C}$ .**Fe-Mo-C;  $t = 17$  to  $19^\circ\text{C}$ ;  $t_H = 950^\circ\text{C}$  (219)**

Mo	C	$\rho_N$	$\rho_H$
0.45	0.19	16.2	17.8
1.00	0.16	16.5	17.1
2.20	0.14	18.2	20.0
4.50	0.29	30.2	31.8
0.50	0.74	18.1	37.6
1.21	0.81	23.4	39.5
1.98	0.81	25.6	40.7

**Fe-Mo-C.—(Continued)**

0°C (176)

Mo	C	$\rho_A$	$\rho_O$
0.95	0.283	15.17	21.68
0.95	0.283	15.36*	17.91†

\* After straining,  $\rho_A = 15.27$ .†  $\rho_Q = 19.79$ ,  $t_Q = 900^\circ\text{C}$ .**Fe-Mo-Cr-Si-Mn-C-(P, S) (50)**5.07Mo, 3.98Cr, 0.90Si, 0.33Mn, 0.013P;  $25^\circ\text{C}$ ;  $t_Q = 940^\circ\text{C}$ 

S	C	$\rho_A$	$\rho_Q$
0.042	1.67	40.03	65.83
0.008*	0.220*	54.73	54.08

\* After decarbonization.

**Fe-Mo-Cr-V-C (46)**

Mo	Cr	V	C	$\rho_{TD}^*$	$\rho_{HM}$
10	2	0.3	0.5	38.9	37.0

\*  $t_D = 1000^\circ\text{C}$ .**Fe-Mo-Mn-(Si, C, etc.)**

Mo	Mn	$\rho_{TD}^*$	$\rho_{HM}$	Lit.
2	1	20.6	22.3	(46)

\*  $t_D = 1000^\circ\text{C}$ .0.025S, 0.016P, 0.020As, 0.0045N; 16 to  $20^\circ\text{C}$ ; v. also Table 4 (268, 269)

Mo	Mn	Si	C	$\rho_A$	$\rho_N$
1.030	0.218	0.047	0.195*	13.48	14.51
1.054	0.230	0.087	0.445	14.77	16.55
1.018	0.270	0.122	0.869	18.55	20.47
1.096	0.250	0.124	1.215	19.54	20.32
2.176	0.216	0.064	0.246	13.55	16.73
2.181	0.270	0.075	0.442	14.97	16.42
2.186	0.263	0.078	0.883	16.13	18.80
2.109	0.238	0.071	1.210	18.47	21.72
2.540	0.205	0.122	1.360	20.13	21.79
4.110	0.242	0.036	0.190	14.95	16.40
4.009	0.292	0.038	0.487	14.89	16.39
4.002	0.230	0.051	0.865	15.53	18.42
4.019	0.230	0.039	1.060	16.92	19.37
8.012	0.216	0.049	0.135†	23.70	25.76
8.167	0.274	0.056	0.361	15.32	17.20
8.109	0.252	0.080	0.445	14.38	16.79
7.847	0.230	0.041	0.775	15.38	17.87
7.920	0.234	0.075	1.125	16.13	18.86

\* 0.005% Al.

† 0.004% Al.

**Fe-Mo-Ni-Si; v. Fe-Ni-Mo-(Si, C)****Fe-Mo-V-(C) (46)**

Mo	V	C	$\rho_{TD}^*$	$\rho_{HM}$
4	0.6		22.6	17.8
5	1.0		25.0	22.9
8	0.5		25.4	25.1
10	0.3		27.2	27.3
10	0.5		30.3	30.7
10	1.0		29.4	30.1
10	1.0		32.1	30.1
8	0.3	0.6	27.8	22.6
10	0.3	0.4	26.6	17.1
10	1.0	0.4	19.9	24.2

\*  $t_D = 1000^\circ\text{C}$ .



## INTERNATIONAL CRITICAL TABLES

## Fe-Ni (146)

For nickel steels and named alloys containing mainly Fe and Ni, see Fe-Ni-C.

$\delta_1 = 1.46$  (9); at  $18^\circ\text{C}$ ,  $\delta_2 = 7$ ,  
 $\delta_3 = 9$ ,  $\delta_4 = 13$ ;  $T_{p_{100}}$  (45,  
46, 193)

Ni	$\rho$
0	12.1
0.27	13.1
0.56	15.4
1.07	16.9
1.93	16.4
7.05	26.9
8.17	26.7
10.20	28.6
11.29	29.4
12.07	30.3
13.11*	34.8
19.21	36.2
22.11	38.7
25.20	63.2
26.40	65.5
28.42	82.0
35.09	81.1
47.08	44.7
75.06	22.1
100.00	12.4

\* +0.89% C.

Ni (76)	$\rho_0$	$\alpha$
95	29.45	2.01

Ni (137)	$\rho_{10}$	$\Delta_{100}$
4.0	20.9	2.0
7.0	25.2	2.3
13.0	33.0	1.8
14.0	33.9	1.6
18.0	35.9	0.84
21.0	38.8	1.8
22.11	40.0	1.8
26.40	35.9	1.6
35.09	92.0	1.1
40.0	74.1	2.2
47.08	47.5	3.6
90.0	15.5	3.4

Electrolytic;\*  $t_A = 902$  to  
 $1064^\circ\text{C}$ , vac (301)

Ni	$\rho_A$
0.50†	11.5
1.01	12.7
1.48†	13.8
1.96†	14.9
2.44†	16.1
2.84	17.1
3.85†	19.4
4.62	20.3
5.67	22.0
7.33	24.8
8.00†	25.2
9.61	27.1
14.92	29.8
15	30†
30	82‡
34.81	80.4

## Fe-Ni.—(Cont'd)

Ni	$\rho_A$
(200)	
0	12
17	38.2
29	79.5
34	86.3
81	23.9
93	18.1
98	11.9
100	11.8
(238)‡	
0	12
5	29
10	31
15	39
20	39
25	40
30	87
35	94
40	81
45	48
50	43
55	41
60	30
65	27
70	27
75	19
80	18
85	20
90	22
95	19
100	9

\* Impurities in Fe = 0.005Al, tr. (Cu, Mn, P, Si), 0.003S, 0.014C; in Ni = 0.250Fe, tr. Mn, 0.001P, 0.006S, 0.040Si, 0.030C. Amount of Ni in alloy determined by analysis excepting those marked "†."

† Amount of Ni added to the Fe.  
‡ Unchanged by precooling to  $-70^\circ\text{C}$ .

§ After precooling to  $-70^\circ\text{C}$ ,  $\rho_{10} = 38$ ; to  $-185^\circ$ ,  $\rho_{10} = 32$ .

|| Impurities in Fe = 0.03Cu, 0.06Mn, 0.01P, 0.01S, 0.01Si, 0.08C.

(105, 193)

Ni	$1000\Delta_i$
22.0*	784 - 0.13t
26.2	844 + 0.01t
28.7	700 - 0.20t
30.8	897 - 0.43t
35.0	1561 - 1.69t
35.7	1161 - 1.68t

\* +3% Cr.

0 to  $370^\circ\text{C}$  (214)

Ni	$\rho_0$	$\alpha$	$\beta$
25	76.2	1.15	-0.59

$10^{-10}\delta_{tr} = (\rho_{tr} - \rho) \div \rho$ ;  
 $10^{-4}\delta_H = (\rho_H - \rho) \div \rho$  (274);  
 $\rho_{tr}$  = value of  $\rho$  when longitudinal traction is  $1 \text{ g cm}^{-2}$ ;  $\rho_H$  = value of  $\rho$  when longitudinal magnetizing force is  $1 \text{ cgsm unit}$ .

## Fe-Ni.—(Cont'd)

Ni	$\rho_{Dj}$	$\rho_A$	$\delta_{tr}$	$\delta_H$
0	12.09	10.74	+13.23	+23.35
22	47.98	75.08	+7.53	+3.06
25	60.94	78.72	+6.64	+1.48
30	55.08	87.93	-1.34	+4.56
100	17.57	17.36	-40.8	+80.7

## Fe-Ni-C (246)

$t$	$\rho$
25.2% Ni; 0.35% C	
16.0	77.85
56	81.43
99	83.60
137	85.24
171	86.71
201	88.41
233	89.65
268	90.89
305	92.50
332	93.67
345	94.25
368	95.19
389	95.95
411	96.57
438	97.70
469	98.89
492	99.53
537	100.8
549	101.4
561	101.7
577	102.1
608	103.3
643	103.9
675	105.1
715	105.6
732	106.5
762	107.0
792	107.7
818	109.0
843	109.5
885	110.9
903	111.4
914	111.6
930	111.4
947	111.7
977	112.3
995	112.8
970	112.4
945	112.0
926	111.5
906	111.2
895	110.8
875	110.4
841	109.5
804	108.9
777	108.0
745	107.1
610	103.5
580	102.5
550	101.8
510	100.6
305	93.89
270	92.93
241	91.86

## Fe-Ni-C.—(Cont'd)

$t$	$\rho$
25.2% Ni; 0.35% C	
177	89.10
156	88.75
35	84.90
30.6% Ni; 0.34% C	
167	87.28
262	91.23
291	92.37
318	93.68
358	94.82
385	95.76
413	96.70
439	97.64
478	98.96
509	99.91
553	101.2
574	101.8
600	102.5
625	103.3
653	104.1
681	104.6
701	105.2
747	106.1
780	107.1
807	107.6
834	108.4
860	109.1
885	109.7
903	110.1
917	110.5
868	109.3
825	108.4
794	107.6
767	106.9
746	106.3
710	105.0
683	104.4
653	103.7
614	102.5
582	101.4
544	100.5
515	99.53
480	98.21
453	97.27
423	96.32
392	95.00
360	93.87
320	92.37
270	90.67
60	81.81
35.25% Ni; 0.33% C	
16	81.87
90	88.09
124	89.79
169	92.33
207	94.31
243	95.59
275	96.86
310	97.85
340	98.98
370	99.97
423	101.1



Fe-Ni-C.—(Cont'd)

$t$	$\rho$
35.25% Ni; 0.33% C	
463	101.2
467	100.7
467	98.13†
516	99.26
516	98.84†
571	99.69
527	98.70
500	97.71
462	96.86
454	96.86
441	96.86
422	96.58
369	95.16

\* For Ni-steel, 30% Ni,  $\rho = 85$ ;  $\alpha = 0.8$  if  $20^\circ < t < 100^\circ$  (148).

† Constant after 75 min.

‡ Constant after 20 min.

Ni-steel (219); cf. (27)

$t = 20$  to  $21^\circ\text{C}$ ;  $t_0 = 975^\circ\text{C}$

Ni	C	$\rho_N$	$\rho_Q$
2.23	0.07	16.6	20.0
5.23	0.12	22.2	22.4
7.13	0.12	24.9	25.8
10.10	0.13	28.7	28.6
12.07	0.12	30.1	30.1
15.17	0.11	32.8	32.5
20.40	0.18	33.5	33.3
25.85	0.16	40.3	37.8
30.00	0.12	82.4	82.4
1.97	0.21	17.7	19.3
4.90	0.20	23.7	24.9
7.59	0.23	25.4	27.8
9.79	0.21	32.0	32.0
12.29	0.22	34.9	35.0
20.01	0.22	44.7	43.1
25.06	0.23	72.0	73.2
27.87	0.19	82.6	82.6
2.20	0.80	21.9	36.6
4.90	0.78	31.4	46.2
7.09	0.81	37.0	50.2
9.79	1.05	40.2	51.7
12.27	0.76	49.0	55.2
15.04	0.80	71.0	70.6
20.01	0.80	74.8	70.8
25.06	0.79	80.4	79.1
29.96	0.81	85.4	85.4

Ni(220)	C	$\rho_s^*$	$\rho_f^*$
7.0	0.6	42.9	30.6
7.0	0.75	44.5	31.0
7.1	0.8	44.9	33.6
9.7	0.35	36.1	30.7
9.9	0.8	55.9	40.0
11.7	0.5	55.3	45.7
12.2	0.4	40.4	36.0
15.0	0.3	69.7	49.0

\* For  $\rho_f$ , annealed from  $1000^\circ\text{C}$ , cooling in 4 to 5 hr; for  $\rho_s$ , annealed from  $1300^\circ\text{C}$ , cooling in ca. 3 days.

Fe-Ni-C.—(Cont'd)

$0^\circ\text{C}$ ;  $t_0 = 900^\circ\text{C}$  (176)

Ni	C	$\rho_A$	$\rho_O$	$\rho_Q$
1.07	0.072	13.17	14.02	12.97
3.37	0.163	18.59	20.69	18.48
5.35	0.199	22.35	23.18	25.62
5.85	0.199	22.28*	22.96	

\* After straining = 22.16.

Effect of chilling (123);  $t_A = 900^\circ\text{C}$ ;  $\rho_c = \rho_A$  after cooling in liquid air

Ni	$\rho_A$	$\rho_c$
0	19.85	19.85
4.6	27.6	27.5
9.2	35.6	36.2
13.8	37.75	39.05
18.5	45.05	41.3
21.2	49.7	44.85
23.6	54.9	42.9
25.8*	69.0	38.75
27.7	93.4	41.65
29.1	98.0	42.55
30.5	92.6	51.3
32.8	99.0	99.0
36.9	80.0	
55.4	39.05	
73.8	27.4	
83.0	21.8	
92.3	20.0	

\* For 25% Ni, ca. 74% Fe: Magnetizable form,  $\rho = 52$ ,  $\alpha = 1.32$  at  $20^\circ$ ,  $\alpha = 4.0$  just below  $600^\circ$ ,  $\alpha < 1.32$  above  $600^\circ$ ; nonmagnetizable form,  $\rho = 72$  (129).

Hadfield's 4.35% Ni-steel (63)

$t$	$\rho_t$
-197.1	19.468
-106.1	23.750
-81.9	24.897
0	29.452
+ 0.95	29.515
16.15	30.402
91.15	35.185

$\alpha_{16} = 2.01$

Named alloys:

Cx	Climax
FN	Ferronickel
Ir	Invar
Pe	Kruppin, v. Vn
Vn	Platinite
	Vestalin

Ni	$\rho$	$\alpha$
Cx, * FN (65, 66, 175); $20^\circ\text{C}$		
25	80-83	0.8-0.98
	Vn (160)	
28	83-85	0.7-1.3
	Ir; $0^\circ\text{C}$	
36	75	2.0
	Pe; $0^\circ\text{C}$	
46-48	45	3

Ni	$\rho$	$\alpha$
FeNi, 51.4% Ni (135)		
Cx	87	0.67
FN	28	2.1

\* May contain 1% Mn.

Fe-Ni-Cr (135); v. also Ni-Cr-(Fe, Mn) and Ni-Cr-Fe

Ni	$\rho_{20}$	$\alpha_{20}$
9.1% Cr		
0	41.13	2.23
22.7	74.39	0.84
45.45	95.94	0.56
68.2	93.45	0.40
90.9	67.80	0.37

13.04% Cr		
0	41.16	2.33
21.76	76.88	1.05
43.48	90.40	0.59
65.2	101.30	0.21
86.96	84.10	0.20

16.7% Cr		
0	52.07	2.47
20.8	79.35	0.91
41.6	103.67	0.34
50	105.38	0.23
62.5	108.04	0.21
83.3	96.90	0.12

Fe-Ni-Cr-C, Steel (12, 13);  $18^\circ\text{C}$ 

Ni	Cr	C	$\rho_A^*$	$\rho_O$
2.00	2.00	0.90	25.3	25.6
2.50	1.75	0.31	27.7	35.1
2.50	4.50	0.41	35.1	43.0
2.75	0.75	0.25	23.9	24.9
3.25	1.75	0.86	28.5	40.9
12.24	2.01	0.64	52.1	55.2

\*  $t_A = 1000^\circ\text{C}$ .

Ni	Cr	C	$\rho$	$\alpha$	Lit.
10	10	1	69.7*		(46)
Steel; v. also Ni-Fe-Cr					
7	18		70	1	(148)
62	12		100	0.2	

\*  $T_{D1000}$ ;  $\rho_{Hm} = 73.8$ .

Fe-Ni-Cr-Mn (200)

Ni	Cr	Mn	$\rho$
2	25	3	86.5
15	15	6	78.6
16	23	2	85.7
18	15	3	84.2
22	4	3	75.1
29	4	2	83.0
35	10	6	99.0
39	16	3	111.0
49	10	6	111.0
56	19	6	110.0
60	10	6	91.0
66	19	5	105.0

Alloy No. 4 (134); for No. 3, v. Ni-Cr-Fe  
Ni, 27.62; Cr, 21.10; Mn, 0.85

$t'$	$\rho$	$t$	$\rho$
20	103.45	700	127.0
300	115.9	800	129.0
400	119.4	900	131.0
500	122.3	1000	132.85
600	125.0		



## Fe-Ni-Cr-Mn-(P, S, Si, C)

Ni, 1.50; Cr, 0.57; Mn, 0.486; Si, 0.162; P, 0.012;  $t = 25^\circ\text{C}$ ,  
 $t_Q = 940^\circ\text{C}$ ; before (after) decarbonization (50)

S	C	$\rho_A$	$\rho_Q$	
0.026	0.354	22.33	26.63	Before
0.014	0.017	21.82	21.92	After

Alloy No. 193 (Driver-Harris); v. also Fe-Ni-Cr; Ni, 30; Cr, 2;  
 Mn, 1; C, 0.22 (134)

$t$	$\rho$ (65)	$\rho$ (134)	$t$	$\rho$ (65)	$\rho$ (134)
20	91.4	95.5	500	114.4	136.10
100	97.3	104.35	600	119.4	140.50
200	102.4	114.45	700	121.25	143.6
300	105.9	123.75	800	125.5	146.9
400	110.7	130.35	900	131.4	151.4

## Fe-Ni-Cr-Mn-Mo-C; v. Fe-Cr-Mn-Ni-Mo-C

## Fe-Ni-Cr-Si (46)

Ni	Cr	Si	$\rho_{TD}^*$	$\rho_{Hm}$
10	10	1	70.9	74.2
10	10	2	76.2	78.8
20	10	2	91.8	93.0

\*  $t_{TD} = 1000^\circ\text{C}$ .

Fe-Ni-Cu-C-(Mn);  $18^\circ\text{C}$  (12, 13)

Ni	Cu	Mn	C	$\rho_A^*$	$\rho_O$
5.75	2.75		0.18	38.2	40.0
2.9	2.9	1.5	0.17	24.9	32.7
14.44	2.25	5.90	0.81	80.0	

\*  $t_A = 1000^\circ\text{C}$ .

Fe-Ni-Mn;  $20^\circ\text{C}$  (135)

Ni	$\rho$	Ni	$\rho$
9.1% Mn		16.7% Mn	
0	46.8	41.6	117
24.7	88.0	62.5	105
45.45	94.7	83.3	51.2
13.04% Mn		Ni	Mn
0	58.0	20	20
21.76	88.6	36	9
43.48	98.3	36	11
65.2	88.3	44	6
86.96	41.6	45	4
16.7% Mn		59	7
0	61.0	65	2
20.8	88.6		

Fe-Ni-Mn-Al-C;  $18^\circ\text{C}$  (12, 13)

Ni	Mn	Al	C	$\rho_A^*$	$\rho_O$
14.1	5.3	2.3	0.43	47.8	88.7

\*  $t_A = 1000^\circ\text{C}$ .

## Fe-Ni-Mn-C, Annealed (14)

Ni	Mn	C	$\rho$
0	tr.	0.03	9.46
0.58	0.18	0.26	16.22
1.92	0.72	0.14	18.58
3.82	0.65	0.19	21.63
19.64	0.93	0.19	35.4
31.40	0.82	0.70	77.9
14.55	5.04	0.80	76.1
25.00	5.04	0.60	80.7

Ni (46)	Mn	C	$\rho_{TD}$	$\rho_{Hm}$
5	2	0.6	44.0	35.6
10	1	0.5		32.4

## Fe-Ni-Mn-C.—(Continued)

Steel;  $18^\circ\text{C}$  (12, 13)

Ni	Mn	C	$\rho_A^*$	$\rho_D^\dagger$	$\alpha_D^\ddagger$
1.00	1.00	0.50	28.7	28.63§	1.50
4.00	3.57	0.57	47.5		
19.00	5.04	0.60	82.0	90.62	1.04
25.00	5.04	0.60	89.2	97.52	1.04
30.00	1.50	0.60	88.2	89.17	0.85§
31.40	0.82	0.70	86.0	86.6	0.90
2.57	8.00	1.21	70.2		
14.55	5.04	0.80	83.0	83.11	1.09
9.00	10.25	1.40	74.7		

\*  $t_A = 1000^\circ\text{C}$ .

† Wire.

‡ Wire;  $t = 0$  to  $150^\circ\text{C}$ .

§ At  $18^\circ\text{C}$ .

|| Rolled; for wire,  $\alpha = 0.77$ .

Steel (54); F and  $A_{1000}$ 

Ni	Mn	C	$\rho_{17}$
0	0.95	0.47	20.3
1.2	0.79	0.48	22.6
2.15	0.83	0.44	24.8
4.25	0.82	0.40	29.1
4.95	1.03	0.42	39.3
6.42	0.92	0.52	42.8
7.95	0.79	0.43	43.9
12.22	0.85	0.41	50.5
15.98	0.83	0.45	63.3
19.91	0.96	0.41	75.4

## Fe-Ni-Mn-Cr-Mo-C; v. Fe-Cr-Mn-Ni-Mo-C

## Fe-Ni-Mn-Cu-C; v. Fe-Ni-Cu-C-(Mn)

## Fe-Ni-Mn-Mo-C (46)

Ni	Mn	Mo	C	$\rho_{TD}^*$	$\rho_{Hm}$
10	2	2	0.5	63.5	64.2

\*  $\rho_{TD} = 1000^\circ\text{C}$ .

Fe-Ni-Mn-Si-C;  $18^\circ\text{C}$  (12, 13)

Ni	Mn	Si	C	$\rho_A^*$	$\rho_O$
0.00	0.18		0.22	17.0	18.3
0.00	1.00		0.75	26.9	30.2
1.00	1.00		0.50	28.7	30.7
31.40	0.82		0.70	86.0	
1.92	0.72	0.21	0.14	20.44	21.51
3.82	0.65	0.20	0.19	24.57	24.94
11.39	0.93	0.22	0.18	35.82	38.23
19.64	0.93	0.27	0.19	39.01	43.01
24.51	1.00	0.30	0.16	45.12	55.50
0.58	0.18	0.44	0.26	17.9	18.9
0.58	0.18	0.33	0.26	18.31	19.12
12.70	0.61	0.39	0.81	44.1	46.5
12.10	0.61	0.56	0.98	45.3	47.7
30.00	1.50		0.60	88.2	

\*  $t_Q = 1000^\circ\text{C}$ .

 $t \leq 800^\circ\text{C}$  (25)

Ni	Mn	Si	C	$\rho_{800}$	$D_{800}$
3.03	0.34	0.19	0.70	150.1	3.05
3.62	0.34	0.18	0.57	152.7	4.5
3.73	0.32	0.28	1.21	155.6	4.7



**Fe-Ni-Mn-Si-C.—(Continued)**Steel (50);  $t = 25^\circ\text{C}$ ;  $t_Q = 940^\circ\text{C}$ 

Ni	1/1000%; before decarbonization						
	Mn	Si	P	S	C	$\rho_A$	$\rho_Q$
2.80	677	231	38	30	422	26.76	32.63
3.43	660	226	27	34	365	26.80	31.25
5.00	493	267	10	30	182	28.63	30.33
6.00	580	450	30	60	2130	25.43	29.60

Ni	1/1000%; after decarbonization						
	Mn	Si	P	S	C	$\rho_A$	$\rho_Q$
2.80	677	231	38	20	36	25.40	26.68
3.43	660	226	27	28	20	25.67	26.33
5.00	493	267	10	17	15	26.78	27.58
6.00	580	450	30	40	180	24.19	24.77

**Fe-Ni-Mo-(Si, C) (46)**

Ni	Mo	Si	C	$\rho_{TD}^*$	$\rho_{Hm}$
10	5			47.5	44.6
20	10			76.8	75.8
10	10		0.5	50.5	55.6
10	10		1	49.7	52.7
20	10		1	78.7	79.6
3.3	7.7	2		52.4	53.6

\*  $t_{TD} = 1000^\circ\text{C}$ .**Fe-Ni-Si (301); 0.2% Si;  $t_A = 900$  to  $1000^\circ\text{C}$** 

Ni	$\rho_A$	Ni	$\rho_A$	Ni	$\rho_A$
0.50	12.7	2.90	19.1	9.52	29.6
1.00	14.3	3.85	20.7	15.0	31.0
1.48	15.1	4.76	21.4	30.0	82.0
1.96	16.5	5.67	25.8	34.5	81.3
2.44	18.0	7.00	25.7		

**Fe-Ni-Si-C (46)**

Ni	Si	C	$\rho_{TD}$	$\rho_{Hm}$
10	2	1.0	70.3	54.2

Steel;  $18^\circ\text{C}$  (12, 13)

Ni	Si	C	$\rho_A^*$
1.00	2.00	0.79	50.5
3.25	2.00	0.38	44.0
3.50	3.25	0.22	57.4
12.10	0.56	0.97	45.0†
12.70	0.39	0.81	43.0†

\*  $t_A = 1000^\circ\text{C}$ ;  $t_{TD} = 1000^\circ\text{C}$ .

† Contains 0.61% Mn.

**Fe-Ni-Si-Mn; cf. Fe-Ni-Si;  $A_{900}$  (301); 0.2% Si, 0.1% Mn**

Ni	$\rho$	Ni	$\rho$
8.0	26.2	50.0	45
10.0	28.9		

**Fe-Ni-Ti;  $A_{900}$ ; vac (301)**

Ni	Ti	$\rho$
9.9	0.20	27.5
15.0	0.20	30.8
50.0	1.0	47.5

**Fe-Ni-V (46)**

Ni	V	$\rho_{TD}^*$	$\rho_{Hm}$
5.0	0.3	24.6	22.3
5.0	0.6	25.0	24.5
10.0	0.3	29.4	30.1
10.0	0.6	32.2	31.2

**Fe-Ni-W (46)**

Ni	W	$\rho_{TD}^*$	$\rho_{Hm}$
15	5	44.9	45.8

\*  $t_{TD} = 1000^\circ\text{C}$ .**Fe-P**

Mn, 0.40–0.57; Si, 0.17–0.25; S, 0.05–0.08; C, 0.11–0.155

 $t_A = t_Q = 900^\circ\text{C}$  (4)

P	$\rho_O^*$	$\rho_A$	$\rho_Q$
0.012	17.0	17.2	16.6
0.100	17.6	17.2	18.0
0.144	18.2	18.1	18.9
0.209	19.6	19.1	20.2
0.245	20.3	19.8	21.6
0.266	20.7	20.8	22.1
0.421	22.2	21.9	24.6
0.560	24.2	23.5	25.0
0.725	24.8	24.2	25.7
0.872	27.6	27.2	28.8
1.153	30.7		32.7
1.242	30.9	30.4	32.2

\*  $\delta_1 = 10.69$  (146); v. also beginning of Fe.**Fe-Pb (46) 0.061% Pb,  $\rho_{TD} = 13.9$ ,  $t_{TD} = 900^\circ\text{C}$** **Fe-S (146);  $\delta_1 = 1.80$ ; v. also beginning of Fe****Fe-Sb (46); 1.0% Sb,  $\rho_A = 20.2$ ,  $t_A = 1000^\circ\text{C}$** **Fe-Se; v. beginning of Fe****Fe-Si;  $\delta_1 = 20.26$  (146); at  $18^\circ\text{C}$ ,  $\delta_2 = 26$ ,  $\delta_3 = 34$ ,  $\delta_6 = 49$  (9)**

Si	$\rho$	Si	$\rho$
$A_{900}$ (299, 300)*		$A_{1100}$ (299, 300)*	
0.001	9.85	2.73	42.00
0.01	9.89	3.40	48.50
0.068	10.75	3.55	48.50
0.148	11.8	4.39	56.10
0.472	16.2	4.44	57.40
0.822	21.3	4.92	66.20
1.74	31.2	$T_{p900}$ (45, 46)†	
3.4	48.5	0.0	12.1
4.44	57.7	0.233	14.7
4.92	66.5	0.603	18.7
		1.033	24.3
		1.897	34.4
		2.826	44.6
		3.334	48.6
		4.655	62.2
		100.0	59.5
		$A_{1000}$ (45, 46)†	
		0.5	19.8
		1.0	15.9
		2.5	44.2
		5.0	36.9
		6.2	74.9
		$H_m$ (45, 46)†	
		0.5	19.5
		1.0	18.6
		2.5	45.7
		4.0	54.8
		4.0	48.6
		5.0	40.3
		6.2	77.2
		* Electrolytic Fe; Si contained 9.50% Fe, 0.016% C.	
		† Elec. Fe; commercial Si.	



Fe-Si.—(Continued)

Si	$\rho$	Si	$\rho$
A (209)		Q (209)	
0.24	15.62	0.95	29.83
0.37	17.21	1.25	30.40
0.67	21.00	1.73	40.80
0.95	24.80	2.35	41.50
1.25	28.90	2.98	47.60
1.73	40.00	5.26	66.00
2.35	39.10		
2.98	46.50		
5.26	64.50		
Q (209)		Fe + 14 to 15% Si, Duriron (69)	
0.24	16.66	$\rho_0$	$\rho_{100}$
0.37	18.88		$\Delta_{100}$
0.67	22.20	63.3	94.4
			4.92

Fe-Si-Al-C (12, 13)  
Steel;  $t = 18^\circ\text{C}$ ,  $t_A = 1000^\circ\text{C}$

Si	Al	C	$\rho_A$	$\rho_O$
2.25	0.5	0.67	43.0	48.6

Fe-Si-C (165, 166)

Si	C	$\rho_A^*$	Si	C	$\rho_A^*$
0.1	0.2	12.5	1.3	0.8	33.5
2.6	0.2	38.5	0.1	1.0	17.8
0.1	0.8	15.8	0.6	1.0	25.5
0.7	0.8	26.5	1.1	1.0	32.0

\*  $t_A = 600^\circ\text{C}$ .

Steel;  $t = 18^\circ\text{C}$  (12, 13)

Si	C	$\rho_A$	$\rho_O$
2.5	0.20	42.1	47.1
5.5	0.26	65.2	68.8

Fe-Si-Mn-C-(S, P) (209); cf. Fe-Mn-C-(P, S, Si), Fe-Mn-P-(C, Si, S), Fe-Mn-Si-C-(P, S), Fe-C-x

Si	Mn	S	P	C	$\rho_A$	$\rho_Q$	$\rho_O$
0.24	0.41	0.064	0.033	0.12	15.62	16.66	16.98
0.37	0.3	0.049	0.041	0.1	17.21	18.88	18.95
0.67	0.23	0.044	0.044	0.11	21.0	22.2	22.2
0.95	0.36	0.043	0.040	0.11	24.8	29.83	26.2
1.25	0.5	0.042	0.043	0.15	28.9	30.4	30.6
1.73	0.56	0.04	0.045	0.15	40.0	40.8	42.0
2.35	0.29	0.058	0.04	0.12	39.1	41.5	42.5
2.98	0.40	0.045	0.043	0.13	46.5	47.6	49.4
5.26	0.6	0.04	0.031	0.13	64.5	66.0	66

Steel (50, 128);  $t = 25^\circ\text{C}$ ;  $t_Q = 940^\circ\text{C}$

Si	Mn	S	P	C	$\rho_A$	$\rho_Q$	$\rho_O$
0.314	0.275	0.032	0.697	0.045	25.00	26.57	
0.314	0.275	0.046	0.697	1.02	30.12		
0.502	7.970	tr.	0.128	4.510*	105.20†		
0.764	0.386	0.467	0.458	2.036†	56.61†		
1.476	0.610	0.105	0.435	2.581§	62.86†		
2.044	0.173	0.042	0.151	3.455	114.00†		
3.438	0.694	0.024	0.133	0.685	61.85†	61.95¶	61.63*
3.649	0.122	0.017	0.03	0.076	53.60	54.05	
3.649	0.122	0.025	0.03	0.094	54.10	55.22	

Si	Mn	S	P	C	$\alpha_{25}$	$\beta_{25}$	Lit.
1.20	0.29	0.048	0.156	2.30	1.37**	3.05**	(199)
1.20	0.29	0.048	0.156	2.30	0.74†	1.3†	

\* Spiegeleisen. †  $t = 0^\circ\text{C}$  (128). ‡ White cast iron; graphitic C = 0. § Mottled cast iron; graphitic C = 1.477%. || Gray cast iron; graphitic C = 2.064%. ¶  $t = 0^\circ\text{C}$ ; oil-hardened (128). \*\* Malleable cast iron.

Fe-Si-Mn-Cr-C-(P, S); v. Fe-C-x

Fe-Si-Ni-C; v. Fe-Ni-Si-C					
Fe-Si-Sn; v. Fe-Sn-(P, Si)					
Fe-Sn; $T_{p900}$ (46)					
Sn	$\rho$	Sn	$\rho$	Sn	$\rho$
0.228	13.0	0.717	21.1	3.5	25.0*
0.342	13.3	1.568	22.4	5.0	47.4†
0.686	15.4	2.059	29.8		

\*  $A_{1000}$ ;  $\rho_{Hm} = 24.1$ . †  $A_{1000}$ .

Fe-Sn-(P, Si) (46)

Sn	P	Si	$\rho_A^*$	$\rho_{Hm}$
1.0		1.0	19.6	28.1
3.0	0.23		25.6	25.6

\*  $t_A = 1000^\circ\text{C}$ .

Fe-Ta-C, Steel;  $t = 25^\circ\text{C}$  (219)

Ta	C	$\rho_N$	$\rho_H$
0.09	0.12	14.1	14.4
0.15	0.17	14.6	14.8
0.6	0.18	14.8	15.1
1.05	0.16	14.8	15.2

Fe-Ti-C, Steel;  $t = 18^\circ\text{C}$ ;  $t_H = 950^\circ\text{C}$  (219)

Ti	C	$\rho_N$	$\rho_H$
0.42	0.11	13.1	13.6
0.88	0.11	13.8	14.3
1.40	0.14	15.1	15.5
2.57	0.14	16.1	17.0
0.32	0.76	19.8	32.9
0.64	0.70	21.0	32.3
0.72	0.62	21.4	31.0
2.57	0.61	22.2	31.5
4.63	0.63	25.1	34.3
8.71	0.65	28.7	37.9

Fe-V-C, Steel;  $t = 16$  to  $23^\circ\text{C}$ ;  $t_H = 1000^\circ\text{C}$  (219)

V	C	$\rho_O$	$\rho_H$
0.60	0.13	14.0	15.7
0.75	0.14	15.1	19.9
1.04	0.11	16.2	21.7
1.54	0.13	18.8	21.9
2.98	0.19	30.1	31.8
5.37	0.38	31.7	31.6
7.39	0.13	38.6	38.4

V	C	$\rho_N$	$\rho_H$
0.25	0.82	21.4	38.2
0.60	0.72	21.7	37.7
0.80	0.89	22.4	42.6
1.15	0.67	19.3	31.5
2.89	0.95	22.5	31.8
4.99	1.08	20.9	27.6
7.85	0.74	37.5	37.5
10.25	0.86	107.2	107.0

Fe-V-Si (46)

V	Si	$\rho_A^*$	$\rho_{Hm}$
10	2	75.5	78.9

\*  $t_A = 1000^\circ\text{C}$ .



Fe-W; at 18°C,  $\delta_2 = 4$ ,  $\delta_3 = 5$ ,  $\delta_4 = 6$  (9)

W	$\rho$	W	$\rho$
Tp <sub>900</sub> (46)		A <sub>1000</sub> (46)	
0.406	13.4	9.0	16.5
0.93	13.6	12.0	17.8
2.33	15.1	16.0	19.3
3.35	16.1	18.0	18.7
5.98	16.2	Hm (46)	19.8
9.85	17.1	2.0	
13.64	20.2	4.0	
23.87	18.5	6.0	
A <sub>1000</sub> (46)		8.0	19.9
2.0	17.6	9.0	23.0
4.0	15.4	12.0	20.7
6.0	16.1	16.0	24.2
8.0	18.2	18.0	23.4

Fe-W-C;  $t_{TD} = 1000^\circ\text{C}$  (46)

W	C	$\rho_{TD}$	$\rho_{Hm}$
5.0	0.5	24.5	18.5

Steel;  $t = 15$  to  $20^\circ\text{C}$ ;  $t_H = 1000^\circ\text{C}$  (219)

W	C	$\rho_N$	$\rho_H$
0.41	0.12	12.8	13.8
0.93	0.11	13.5	14.3
1.75	0.11	15.8	17.1
4.96	0.13	19.5	21.1
6.90	0.13	23.3	23.4
11.89	0.17	20.9	24.5
14.37	0.20	22.6	24.6
20.71	0.22	23.1	25.3
24.35	0.22	25.3	25.2
27.05	0.28	20.7	25.8
0.40	0.86	22.4	39.1
0.95	0.66	20.9	39.6
2.75	0.79	24.3	40.9
4.68	0.33	28.1	41.2
9.99	0.81	26.9	39.5
14.75	0.71	26.5	32.3
19.25	0.74	25.3	31.0

 $t = 0^\circ\text{C}$  (128); 0.036Mn, 0.043Si, 0.047P; oil-hardened

W	C	$\rho_A$	$\rho_H$	$\rho_F$
4.649	1.357	22.50	22.74	22.49

 $t = 18^\circ\text{C}$  (27, 28)

W	C	$\rho_A$	$\rho_{TD}$	$\rho_O$
0.3	0.35	18.4	18.2	17.4
7.0	0.40	42.7	44.3	44.3
10.0	0.50	23.5	26.7	38.2
17.0	0.50	47.8	51.0	51.9
22.0	0.80	62.5	67.5	60.3

$t_A$	900°	900°	1100°	Lit.
C	0.3	0.6	0.6	(125)

W	$\rho_A$	$\rho_A$	$\rho_A$
0	16.5	19.4	
0.5	18.3	21.4	
1.0	19.4	21.4	23.53
2	20.4	21.8	
3		21.6	28.32
5	21.1		
6	21.0	21.8	33.11

Fe-W-C.—(Continued)

$t_A$	900°	900°	1100°	Lit.
C	0.3	0.6	0.6	(125)
W	$\rho_A$	$\rho_A$	$\rho_A$	
10		23.0		
15	25.6	24.8		
20	29.8	28.1	44.66	
25	37.0	32.8	47.62	

Fe-W-Cr-(Si, C); v. Fe-Cr-W-(C, Mo, Si, V)

Fe-W-Cu-Cr-C, Steel;  $t = 18^\circ\text{C}$ ;  $t_A = 1000^\circ\text{C}$  (12, 13)

W	Cu	Cr	C	$\rho_A$	$\rho_O$
2.0	2.0	1.75	0.48	31.3*	49.0

\*  $\rho_D = 31.6$ ,  $\alpha_D = 2.04$  for 0 to  $150^\circ\text{C}$ .

Fe-W-Mn-C (14); cf. Fe-Mn-W-C

W	Mn	C	$\rho_A$
1.00	0.11	0.16	13.65
3.50	0.28	0.28	16.22
15.50	0.28	0.76	24.3
3.25	2.25	0.40	25.16
10.00	3.25	1.50	27.84

Steel;  $t = 18^\circ\text{C}$ ;  $t_A = 1000^\circ\text{C}$  (12, 13)

W	Mn	C	$\rho_A$	$\rho_O$
1.0	0.11	0.16	15.1	15.8
4.5	0.28	0.28	18.0	21.5
7.5	0.20	0.38	19.2	24.6
15.5	0.28	0.76	26.6	35.7

Fe-W-Mn-Cr-Si-C-(P, S) (50)

5.04W, 0.32Mn, 0.24Cr, 0.12Si, 0.018P;  $t = 25^\circ\text{C}$ ,  $t_Q = 940^\circ\text{C}$ ; before (after) decarbonization

S	C	$\rho_A$	$\rho_Q$	
0.016	0.083	19.52	29.90	Before
0.006	0.026	24.30	24.07	After

Fe-W-Mn-Si-C-(P, S)

Steel; oil-hardened; no S;  $t = 0^\circ\text{C}$  (128)

W	Mn	Si	P	C	$\rho_H$
4.649	0.036	0.043	0.047	1.357	22.74*
3.444	0.625	0.021	0.028	0.511	36.04
2.353	0.312	0.151	0.089	0.855	44.27†

\*  $\rho_A = 22.50$ . † Very hard. $t_A = t_N = 950^\circ\text{C}$ ;  $t_H = 740$  to  $810^\circ\text{C}$  (267)

W	Mn	Si	S	P	C	$\rho_A$	$\rho_N$	$\rho_H$
3.25	0.065	0.044	0.055	0.010	0.144	17.31	16.63	19.24
3.24	0.071	0.050	0.050	0.010	0.218	17.50	17.63	19.33
2.92	0.170	0.027	0.014	0.018	0.27		17.63	20.20
3.11	0.075	0.060	0.050	0.010	0.48	18.87	19.12	23.87
3.18	0.140	0.033	0.035	0.012	0.53	18.40	18.46	25.64
3.17	0.080	0.078	0.054	0.010	0.57	18.56	19.98	26.68
3.08	0.093	0.039	0.040	0.012	0.89	17.64	18.76	36.6
3.09	0.055	0.040	0.042	0.012	1.07	16.97	18.43	38.70

 $t = 15^\circ\text{C}$ ;  $t_{TD} = 1100^\circ\text{C}$  (25, 165, 166); v. also Table 4

W	Mn	Si	C	$\rho_{TD}$	$\rho_O$	$\rho_i'$	$D_{800}$
5.	0.3	0.02	0.6	37.8	21	29.4*	
2.9	0.4	0.2	0.55	32.4	18	79.8†	1.5
2.7	0.44	0.3	0.76	37.0	18.5	84.6†	3.2
2.7	0.38	0.32	1.11	44	20	81.0†	1.83

\*  $t' = 780^\circ\text{C}$ . †  $t' = 800^\circ\text{C}$ .



Fe-W-(Mo, Cr, V, C) (46)

W	Mo	Cr	V	C	$\rho_{TD}^*$	$\rho_{Hm}$
10	10	2	0.3	0.4	38.3	45.8
16	5	2	0.3	0.5	38.8	44.5
4.0			0.4		20.0	18.1
7.0			0.3		22.2	20.3
4.0			0.4	0.5	38.9	23.2
4.0			0.4	0.6	35.0	23.0
4.0			0.4	0.8	43.1	24.1
7.0			0.3	0.6	33.3	24.1

\* $t_{TD} = 1000^\circ\text{C}$ .

Hg-Ag

Ag (47)	$\rho_{20}$	$\alpha$
0	95.75	0.86
0.0015	95.52	0.91
0.003	94.93	0.87
0.005	94.74	0.84
0.008	94.02	0.84
0.010	93.39	0.84
0.014	91.13	0.92
0.020	87.73	0.92
0.060	71.63	0.94

Ag (187)	$\rho_t$	$t$
0.01	93.85	13.1
0.025	93.7	13.2
0.05	93.6	13.4
0.1	93.25	13.0
0.1995	92.75	13.3
0.4975	91.5	13.0
0.99	88.6	13.0

Ag (282)	$\rho_{18}$	$\alpha$
0.249	95.5	1.18
0.498	95.5	1.05
0.990	94.9	0.81

Hg-Bi; v. also Bi-Hg; for Ag,  $\rho_0 = 1.54$  (298)

Bi	$\rho_t$	$t$
0.05	93.7	13.05
0.1	93.6	13.15
0.1995	93.26	13.05
0.4975	92.6	13.45
0.99	92.12	13.25

For Hg,  $\rho_0 = 94.07$ ,  $\rho_{20} = 95.76$  (159)

0.061	95.5	20
0.15	95.2	20
0.276	94.8	20
0.448	94.8	26
0.608	94.3	25
0.749	93.95	24.2
0.946	93.55	25.4
1.071	93.3	25.0
1.225	93.0	24.7

Bi	$a$	$b$
0.276*	1.0095	31
0.749*	1.0222	48
1.393*	1.0356	68
1.688*	1.0403	80
1.885*	1.0436	84
2.495*	1.0510	112
2.97*	1.0558	115
Sat.†	1.0100	1120

\* Unsaturated,  $t \geq 80^\circ\text{C}$ .

† Saturated;  $15^\circ < t < 40^\circ$ .

Hg-Bi.—(Cont'd)

Bi (282)	$\rho_{18}$	$\alpha$
0.1	95.9*	
0.249	95.3	0.89
0.498	94.4	0.88
0.990	93.25	0.89
0.238		1.106†
0.498		1.150†
0.943		1.203†

\*  $t = 18.6^\circ\text{C}$ , from (184)

† From (18)

Hg-Pb (71)

20% Bi, 20% Pb	
$\rho_t$	$t$
92.3	0
95.0	97.5
97.16	143
99.17	181.5
99.86	191.5
00.2	196.5
100.9	214

Hg-Ca (23)

Ca	$\rho_{50}$	$\alpha$	$\beta$
0.12	97.02	0.834	1.442

$50^\circ < t < 300^\circ$

Hg-Cd (159)

Cd	$\rho_t$	$t$
0.016	95.3	17.0
0.032	95.25	18.0
0.065	94.9	16.1
0.098	94.7	16.6
0.145	94.4	16.8
0.19	94.0	16.9
0.28	93.4	16.7
0.375	92.8	17.7
0.47	92.1	17.0
0.55	91.5	17.1
0.64	90.9	15.9
0.735	90.2	16.0
0.83	89.7	16.7
0.925	89.15	16.5
1.03	88.5	16.8
1.065	88.3	16.9
1.21	87.4	17.0
1.295	87.25	20.1
1.395	86.75	21.3
1.58	85.7	21.3
1.77	84.6	20.2
1.955	83.6	20.1
2.09	82.9	20.0
2.27	82.1	19.9
2.43	81.15	19.4

Hg-Cd.—(Cont'd)

Cd	$\rho_t$	$t$
2.61	80.4	19.6
2.72	79.9	19.7
2.88	79.2	19.7
2.99	78.7	19.6
3.12	78.1	19.4
3.21	77.7	19.4
3.39	76.9	19.4
3.57	76.2	19.7
3.76	75.5	19.8
4.03	74.4	19.8
4.31	73.3	19.4
4.58	72.4	19.3
4.85	71.4	19.6
4.85	71.3	19.6
4.98	70.5	19.3

Cd	$a$	$b$
0.375	1.0292	11
0.735	1.0564	25
1.21	1.0911	36
4.98	1.3455	138

Cd (47)	$\rho_{20}$	$\alpha_{20}$	$\beta_{20}$
0.20	94.36	0.85	1.0
0.43	93.05	0.90	1.0
0.69	91.55	0.79	2.0
0.94	90.20	0.85	1.4
1.50	86.49	0.83	

Cd	$\rho_t$	$\alpha$	$\beta$
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$t = 18^\circ\text{C}$  (282)

0.249	94.8	1.25	
0.498	92.2	0.75	
0.990	89.3	0.86	

$t = ?$  (18)

0.444	1.096		
0.885	1.096		
1.754	1.103		

$t = 50^\circ\text{C}$  (23)

0.51	94.6	0.922*	1.099*
1.47	87.7	0.815*	1.425*

\*  $\alpha_{50}, \beta_{50}; 50^\circ \leq t \leq 300^\circ$ .

Cd (284)	$R$	$t$
2.55	1.085	263.7
9.41	0.778	264.1
23.41	0.561	264.2
33.25	0.490	263.6
50.90	0.425	264.1
71.58	0.399	267.2

Hg-K (122); v. also Table 3

K	$\rho_{20}$
0	95.76*
0.01137	95.96
0.03496	96.29
0.07956	97.45
0.10945	98.26
0.1274	98.65
0.1726	99.72
0.2334	100.9

\* Assumed as basis.

Hg-Li (122)

Li	$\rho_{20}$
0	95.76*
0.001131	95.72
0.003459	95.59
0.01069	95.19
0.01684	94.79
0.02474	94.39
0.02867	94.14

\* Assumed as basis.

Li	$\rho_{50}$	$\alpha_{50}$	$\beta_{50}$
$50^\circ < t < 300^\circ$ (23)			
0.003	98.82	0.943	1.194
0.02	98.32	0.910	1.140
0.04	97.50	0.816	1.393

Hg-Na (122); v. also Table 3

Na	$\rho_{20}$
0	95.76*
0.01070	95.83
0.03339	95.96
0.04430	96.03
0.09990	96.25
0.1387	96.38
0.1944	96.51
0.2468	96.58
0.2824	96.61
0.3104	96.54
0.4338	96.38
0.5893	96.34

\* Assumed as basis.

For Hg,  $\rho_{17} = 95.59$  (280)

Na	$\rho_{107}$	$\alpha_{107}^*$
19.65	124.0	0.54
21.1	123.5	0.40
25.9	119.8	0.13
28.8	115.9	0.32
32.1	110.6	0.16
40.5	93.65	1.30
50.5	74.1	2.38
62.8	55.8	
70.2	40.4	2.26
100	21.74†	12.76

\* If  $107^\circ < t < 133^\circ$ .

† This value unusually great.

Na (232)	$\delta_f$	$t_f^*$
0	76.70	-38.8
Trace	74.50	-40.5
0.658	63.80	-47.93
0.846	59.60	-48.64
1.174	57.70	-48.43
1.560	43.15	-47.85
2.100	42.55	-47.52
2.670	37.40	-47.25

\*  $t_f$  = temperature of fusion.

Hg-Pb

For Ag, $\rho_0 = 1.54$ (298)		
Pb	$\rho_t$	$t$
0.01	93.85	13.2
0.025	93.7	13.05
0.05	93.6	13.2
0.1	93.35	12.3
0.1995	92.77	13.4
0.4975	91.27	13.1



**Hg-Pb.—(Cont'd)**

Pb	$\rho_t$	$t$
0.99	89.1	13.15
1.96	87.5	13.15
3.84	86.27	13.2

Pb (284)	$\rho_t/\rho'$	$t$
0	1.000	266.6
5.94	0.7853	263.7
12.07	0.7150	264.0
24.81	0.6852	264.0
32.83	0.6860	263.7
48.12	0.7150	263.4
51.45	0.7219	264.5
59.46	0.7426	264.1
70.73	0.7654	264.9

Pb (159)	$\rho_t$	$t$
0.03	95.25	17.0
0.06	95.1	18.0
0.121	94.7	16.1
0.182	94.4	16.6
0.269	93.9	16.8
0.358	93.4	16.9
0.52	92.6	16.7
0.69	91.8	17.7
0.863	91.0	17.0
1.009	90.3	17.1
1.182	89.65	15.9
1.354	89.05	16.2
1.53	88.7	16.7
1.70	88.6	16.7

Pb	$a$	$b$
0.69*	1.0400	28
1.354*	1.0714	59
1.70*	1.0855	82
Sat.†	1.0554	1270

\* Unsaturated;  $t \geq 80^\circ$ .† Saturated;  $17^\circ \leq t \leq 24^\circ$ .

Pb (83)	$\rho_0$
0.259	92.51
0.518	91.24
1.036	89.66
1.554	88.80
2.072	88.22

Pb	$\rho_{18}$	$\alpha$	Lit.
0.241		1.109	(18)
0.481		1.110	(18)
0.957		1.111	(18)
0.249	94.1	0.86	(282)
0.498	92.9	0.75	(282)
0.990	90.65	0.87	(282)

**Hg-Pb-Bi; v. Hg-Bi-Pb****Hg-Sn**

Sn	$\rho_t$	$t$
For Ag, $\rho_0 = 1.54$ (298)		
0.01	93.7	12.15
0.025	93.6	12.5
0.05	93.3	12.7
0.1	92.8	13.1
0.1995	91.7	13.2
0.4975	88.85	13.1

**Hg-Sn.—(Cont'd)**

Sn	$\rho_t$	$t$
0.99	86.9	13.2
1.96	83.2	13.0
3.84	77.8	12.8

For Hg,  $\rho_{18} = 95.59$  (184)

Sn	$\rho_t/\rho'$	$t$
0.01	95.4	18.4
0.02	95.3	18.0
0.05	94.95	18.2
0.1	94.4	18.8
0.2	90.55	19.0
0.5	90.4	18.4
0.99	87.85	18.6
1.94	84.55	18.8
3.84	78.8	19.0

Sn (284)	$\rho_t/\rho'$	$t$
0	1.000	247.2
4.09	0.7553	245.3
6.38	0.6990	245.2
10.74	0.6403	246.2
19.50	0.5889	246.2
24.30	0.5840	246.0
33.71	0.5636	247.4
36.01	0.5375	245.6
48.64	0.5269	245.7
54.10	0.5016	246.4
59.62	0.4951	246.0
66.33	0.4829	247.7
71.54	0.4730	247.2
79.11	0.4690	247.2
88.13	0.4535	246.2
100.0	0.4282	247.2

Sn	$\rho_{18}$	$\alpha$	Lit.
0.498	90.0	0.900	(282)
0.990	88.0	0.979	(282)
0.990		1.095	(18)
1.67		1.103	(18)
1.96		1.111	(18)

Sn (83)	$\rho_0$
0.148	92.32
0.297	90.74
0.594	89.02
0.890	87.90
1.187	86.80

For Hg,  $\rho_0 = 94.07$ ,  $\rho_{20} = 95.76$  (159)

Sn	$\rho_t$	$t$
0.054	95.05	20.0
0.12	94.35	20.3
0.211	93.25	20.8
0.353	91.85	21.5
0.457	90.85	21.5
0.533	90.1	21.2
0.613	89.35	21.2

Sn	$a$	$b$
0.211*	1.0265	44
0.457*	1.0544	56
0.702*	1.0795	88
0.787*	1.0885	90
Sat.†	1.0414	1850

\* Unsaturated;  $t \geq 80^\circ\text{C}$ .† Saturated;  $17^\circ < t < 25^\circ$ .**Hg-Sn.—(Cont'd)** $R$  is "relative" value of  $\rho_t$  (282)

$t$	$R$
Sn = 2%	
15.7	8634
91.1	9410
83.2	9330
79.6	9301
69.6	9220
60.7	9152
48.5	9040
39.4	8991
34.8	8961*

Sn = 3%

$t$	$R$
15.8	7608
92.4	8841
79.5	8761
71.1	8731
60.8	8671
50.0	8612
38.9	8598
29.5	8560
16.3	8516

Sn = 4%

$t$	$R$
15.2	9122
68.7	9129
76.1	9536
81.4	9583
91.5	9516
85.4	9471
79.6	9226
74.0	9179
69.0	9136
62.6	8930
58.6	8926
52.3	8883
38.7	8823
22.6	8779

Sn = 5%

$t$	$R$
19.2	8118
89.3	8369
76.2	8334
69.7	8288
59.6	8242
52.0	8220
36.9	8187
19.5	8151
19.7	8110

Sn = 6%

$t$	$R$
14.9	7997
50.7	8117
82.3	8225
89.2	8347
90.7	8442
91.0	8424
73.4	8319
61.6	8259
50.3	8231
32.5	8180
22.2	8131
16.4	8106
15.4	8101

**Hg-Sn.—(Continued)**

$t$	$R$
Sn = 12%	
17.0	1639
34.0	1655
45.0	1656
62.0	1657
84.0	1695
86.0	1725
90.6	1805
92.8	1877
93.8	1877
86.0	1866
83.3	1863
77.5	1795
75.8	1785
70.8	1770
65.0	1759
55.8	1749
48.6	1744
34.3	1725
17.2	1704

\* Suddenly cooled,  $\rho_{16.1} = 8924$ ; after 3 hr,  $\rho_{16.6} = 8920$ ; after 20 hr,  $\rho_{17.0} = 8801$ .**Hg-Tl (210)**

Tl	$\rho_0$	$\alpha_0^*$
0	94.07	0.96
10	80.65	0.77
15.3	74.52	0.63
18.3	72.99	
19.2	65.83	5.66
20.5	55.65	
22.1	46.25	
23.7	37.5	
24.6	32.8	61
26.6	31.8	
27.2	31.6	63.5
27.9	31.6	
29.3	31.8	61.8
30.6	32.1	
31.4	32.5	59
33.1	32.7	57.5
36.6	32.1	58.5
39.5	31.8	58.4

\*  $0^\circ < t < 19^\circ$ .

Tl	$\rho_{75}$	$\alpha_0^*$
0	18.8	
0.6	19.5	
0.8	20.6	
1.6	20.0	
5.4	21.9	
11.6	29.4	
19.2	30.9	
20.8	29.9	
22.6	27.8	
24.6	25.7	3.73
25.5	25.3	
26.6	24.8	3.71
28.2	24.8	3.71
31.4	25.4	3.77
33.5	25.0	
36.6	24.5	4.19
39.5	24.1	4.32

\*  $0^\circ < t < 75^\circ$ .



## Hg-Tl.—(Cont'd)

Tl (23)	$\rho_{80}$	$\alpha_{80}$	$\beta_{80}$
1.0	96.58	0.872	1.241
2.89	93.20	0.814	1.029

## Hg-Zn

Zn	$\rho_t$	$t$
For Ag, $\rho_0 = 1.54$ (298)		
0.01	93.7	13.07
0.025	93.5	13.07
0.05	93.2	13.13
0.1	92.45	13.07
0.1995	91.15	13.13
0.4975	87.6	13.2
0.99	82.27	13.27
1.96	75.5	13.0
3.84	69.9	13.1

For Hg,  $\rho_0 = 94.07$ ,  $\rho_{20} = 95.76$  (159)

0.0095	95.3	17.0
0.019	95.2	18.0
0.038	94.75	16.1
0.057	94.5	16.6
0.085	94.1	16.8
0.113	93.65	16.9
0.165	92.9	16.7
0.22	92.3	17.7
0.275	91.45	17.1
0.32	90.85	17.1
0.375	90.15	15.9
0.43	89.4	16.0
0.49	88.85	16.7
0.54	88.15	16.5
0.605	87.4	16.8
0.625	87.15	16.9
0.70	86.15	17.0
0.755	85.9	20.1
0.815	85.4	21.3
0.926	84.1	20.1
1.038	82.9	20.2
1.147	81.8	20.1
1.227	81.1	20.0
1.335	80.05	19.9
1.429	79.2	20.0
1.538	78.3	19.6
1.607	77.7	19.7
1.703	77.0	19.7
1.765	76.4	19.6
1.844	75.9	19.4
1.880	75.4	19.4
2.007	74.8	19.4
2.065	74.7	19.6

Zn	$a$	$b$
0.219*	1.0347	19
0.432*	1.0667	13
0.713*	1.1074	28
1.43*	1.2071	68
1.648*	1.2350	107
Sat.†	1.1724	5410

\* Unsaturated;  $t = 80^\circ\text{C}$ ; heating to  $80^\circ\text{C}$  reduces the ratio; for 0.713 % Zn the reduction is the greatest and = 0.2 %.

† Saturated;  $17^\circ < t < 22^\circ$ ; at  $23.3^\circ\text{C}$ , ratio is about 0.3 % less than computed.

## Hg-Zn.—(Cont'd)

Zn	$\rho_t$	$\alpha$
$t = 0^\circ\text{C}$ (83)		
0.163	91.70	
0.327	89.56	
0.654	85.59	
0.980	82.15	
$t = 18^\circ\text{C}$ (282)		
0.249	94.0	0.80
0.498	90.45	0.88
0.990	86.9	0.97
Zn	$\alpha$	Lit.
0.761	1.094	(18)
1.51	1.089	(18)
16.5	1.876*	(293)
23.9	1.850*	(293)
28.3	1.814*	(293)
33.3	1.844*	(293)
40.1	1.807*	(293)

\* Mean 30 to  $100^\circ\text{C}$ .

## In-Pb (158)

Pb	$\rho_{25}$	$\alpha^*$
0	9.913	4.38
16.8	16.52	2.75
31.1	24.28	2.45
54.6	27.79	2.28
64.4	31.92	2.25
73.0	32.66	2.33
86.4	30.98	2.71
94.2	28.27	2.75
97.1	25.41	3.44
99.2	22.83	4.00
100.00	21.50	4.24

\* 25 to  $100^\circ\text{C}$ .

## K-Na (203); v. also Table 3

Na	$\rho_{20}$	$\alpha_{20}^*$
53	33.8	1.47

\* 46 to  $125^\circ\text{C}$ .

## K-Rb (152)

Rb	$\rho_0$	$\rho_{25}$	$\rho_{50}^*$
0.00	6.60	7.71	8.82
26.7	8.29	9.49	10.72
39.7	9.05	10.34	16.89
54.9	10.17	11.64	19.01
74.0	11.32	12.92	21.14
85.6	11.60	13.41	22.28
90.0	11.57	13.50	22.58
100.0	11.29	13.16	23.15

Rb	$\rho_{75}$	$\rho_{100}$
0.00	14.43	15.80
26.7	17.46	18.98
39.7	18.42	19.84
54.9	20.75	22.53
74.0	22.88	24.75
85.6	24.16	26.05
90.0	24.58	26.39
100.0	25.32	27.47

\* Note break between 26.7 % Rb and 39.7 % Rb.

## K-Tl; v. Table 3

Mg-Ag; v. Ag-Mg		
Mg-Al; v. Al-Mg		
Mg-Cd; v. Cd-Mg		
Mg-Cu; v. Cu-Mg		
Mg-Pb (264); cf. (265)		
Pb	$\rho_{25}$	$\alpha^*$
0	4.40	4.10
6.00	9.00	1.70
13.20	9.00	1.70
21.00	16.60	0.80
23.20	17.70	0.87
47.37	28.00	0.65
67.00	46.00	1.23
69.68	59.00	1.10
70.90	68.00	1.00
73.77	107.0	0.95
75.17	97.0	1.50
75.50	103.5	1.20
76.00	109.0	1.55
78.11	129.0	1.80
79.00	148.5	2.05
80.10	163.0	1.80
80.30	180.0	1.20
81.80	149.0	2.20
83.30	159.0	2.59
85.00	121.0	2.20
85.50	114.0	2.45
89.27	73.50	2.53
91.66	55.00	2.90
94.60	46.50	2.84
97.25	36.70	2.80
98.4	30.70	3.35
100.0	21.07	4.29

\*  $25^\circ < t < 100^\circ$

## Mg-Sn (265)

Sn	$\rho_{25}$	$\Delta_{100}$
5.5	6.75	1.63
11.2	11.9	1.50
15.3	14.63	1.00
20.0	15.65	1.37
35.2	17.61	2.04
55.5	42.18	1.98
68.9	225	2.24
69.0	413.0	2.76
69.0	430.0	3.01
70.5	463.0	2.75
71.1	1096.0	4.45
72.5	445.0	4.30

Ni; for effect of traction and of magnetic field, v. Fe-Ni

Key or name	Impurities, 1/100 %					
	Co	Cu	Fe	Mn	Si	C
1						3.5
2	99					
3	15	20	tr.		0	0
4	tr.	80	tr.		20	
Elec. Ni		5	15			
Grade A		24	65	8	3	8
5	10	40	60			15
6	50	tr.	150			10

## Mg-Sn.—(Cont'd)

Sn	$\rho_{25}$	$\Delta_{100}$
72.9	260.0	4.27
73.9	283.0	4.36
78.0	161.4	4.28
88.2	35.68	4.46
90.0	37.26	4.49
91.4	30.01	4.45
95.1	21.18	4.31
97.9	15.96	4.43

## Mg-Zn (265)

Zn	$\rho_{25}$	$\Delta_{100}$
14.3	7.175	2.67
52.9	11.0	2.27
56.5	15.13	2.04
67.6	15.54	2.02
70.1	26.78	1.37
80.1	31.12	0.97
84.4	15.88	2.89
86.25	16.90	2.63
86.45	14.2	3.20
91.5	12.51	3.13
96.0	7.8	3.79

Mn-x; see the other metal

## Mo-W (82)

W	$a$
0	4.57
5.8	4.08
11.5	3.75
22.7	3.37
33.5	3.14
43.9	2.99
55.8	2.91
63.7	2.92
73.2	3.04
82.4	3.26
91.4	3.76
94.76	4.01
98.10	4.37
98.49	4.43
98.85	4.46
99.255	4.56
99.618	4.64
100	4.82

## Na-Cd; v. Table 3

Na-Hg, Na-K; v. Hg-Na, K-Na

Na-Pb, Na-Sb, Na-Tl; v. Table 3



## Ni.—(Continued)

Key or name	Impurities, 1/100 %					
	Co	Cu	Fe	Mn	Si	C
7	136	15	44	104	6	
Grade C		40	89	210	18	22
Grade D		16	74	475	13	8

Grade	Elec.	A	C	D
$t$ (134)	$\rho$	$\rho$	$\rho$	$\rho$
20	9.74	10.64*	13.97†	17.80‡
100	14.2	15.21	18.99	22.95
200	20.16	21.92	26.54	29.90
300	27.86	30.1	36.04	37.38
400	35.94	37.44	42.16	41.11
500	38.95	41.15	45.51	43.78
600	41.97	44.12	48.72	46.64
700	45.0	47.24	52.09	49.49
800	48.0	50.31	55.29	52.31
900	51.03	53.61	58.91	55.70
1000	54.91	57.24	62.84	59.10

\*  $\alpha = 5.37$  (65) † Cf. (133). ‡ By (133),  $\rho_{20} = 19.43$ .

Key	$\rho_0$	$\alpha$	$\beta$	Lit.
1	7.7			(237)
2	8.38*	5.21		(136)
3†	9	5.3†	5.5†	(214)
4	10.24	3.7†	6.0†	(214)
5	14.25	3.5†	7.0†	(214)
6	13.25	3.0†	7.0†	(214)
7	11.76§			(139)

\*  $t = 20^\circ\text{C}$ . †  $\Delta_{100} = 5.8$  (214) ‡ From 0 to  $345^\circ\text{C}$ . §  $t = 18^\circ\text{C}$ .

## Ni-Al (136); cf. Al-Ni

Al	$\alpha$	Al	$\alpha$
0.498	3.68	0.99	2.85

## Ni-C; v. Ni

## Ni-Co; v. Ni and Co-Ni

## Ni-Co-Fe-(Mn, Mg, Si, Cu)

Co	Fe	Mn	Mg	Cu	Si	$\rho_{20}$	$\alpha$	Lit.
0.97	0.97	0.97				9.41	4.59	(136)
0.98	0.98					8.82	4.90	(136)
1.06	0.36	1.22	0.11	0	0.07	11.5*		(288)
1.18	0.37		0.12		0.08	9.9†		(288)
1.15	0.43		0.11	0.1	0.08	9.5‡		(288)
1.36	0.44	1.04		0.15	0.06	11.76§	4.4	(139)

\* Same for forged as for cast. † Forged. ‡ Cast. § For  $18^\circ\text{C}$ .

## Ni-Cr (135)

Cr	$\rho_{20}$	$\alpha$
0	10.67	6.00
4.76	45.7	0.970
9.1	67.8	0.370
10	v. Ni-Cr-(Fe, Mn)	
13.04	84.1	0.200
15	v. Ni-Cr-(Fe, Mn)	
16.67	96.9	0.120
18.3	v. Ni-Cr-(Fe, Mn)	
20	99.7	0.140
20	v. Ni-Cr-(Fe, Mn)	

## Ni-Cr-Cu; v. Cu-Ni-Cr

## Ni-Cr-Fe; v. also Fe-Ni-Cr and Ni-Cr-(Fe, Mn)

Cr	Fe	$\rho$ (200)
3	4	46.0
6	4	53.0
7	18	83.1
10	35	107.0
13	16	100.2
15	5	96.8
20	25	93.5
25	20	113.0
29	7	110.0
32	10	110.0
37	11	113.0

## Ni-Cr-Fe.—(Continued)

Alloy No. 3 (134); Cr, 31.35; Fe, 13.77; Mn, 0.00

$t$	$\rho$	$t$	$\rho$
20	114.1	700	123.15
300	119.6	800	123.4
400	121.0	900	124.4
500	122.7	1000	125.3
600	122.75		

## Ni-Cr-(Fe, Mn), Nichromes; cf. Fe-Ni-Cr

	Cr	Fe	Mn	Lit.
Nichr.....	12	28	0	(65)
Nichr.....	11.3	26.3	1.5	(134)
Nichr. II.....	18.7	10.53	1.58	(134)
Nichr. III*.....	15	0	0	(65)
Nichr. III*.....	15.3	0	0	(134)
Nichr. IV†.....	20	0	0	(65)
Nichr. IV†.....	18.3	0	0	(134)
Excello.....	14	0.5	0.5	

Lit.	Nichr. (65, 134)	Nichr. II (134)	Nichr. III (65)	Nichr. III* (134)
$t$	$\rho$	$\rho$	$\rho$	$\rho$
20	109.75	110.7	89.75	97.15
100	112.25		90.75	
200	115.4		92.1	
300	118.1	114.8	93.4	101.3
400	119.9	116.2	94.75	102.5
500	121.4	117.6	95.75	103.5
600	122.2	117.2	95.75	103.4
700	121.4†	117.1	96	103.75
800	123.7	117.4	97.1	104.4
900	125	118.2	98.1	105.7
1000	126.9	119.0	99.75	107.2
$\alpha$	v. infra	0.2-0.15 (65)	0.050‡ (175)	

## Nichrome IV§

$t$	$\rho$ (65)	$\rho$ (134)	$t$	$\rho$ (65)	$\rho$ (134)
20	103	98.0	600	108.5	101.85
100	104.9		700	108	101.65
200	106		800	108.9	101.85
300	106.9	100.75	900	109.4	102.35
400	108	101.75	1000	110.6	103.5
500	108.9	102.6	$\alpha$	0.179 (65)	

\* Kromore. Same nominal composition as Rayo,  $\alpha = 0.102$  (65)†  $\rho_{100} = 122.8$  (134)‡  $t = 20$  to  $50^\circ\text{C}$ ; for  $t = 20$  to  $100^\circ\text{C}$ ,  $\alpha = 0.187$  (65).§ Chromax. Same nominal composition as Chromel A,  $\alpha = 0.11$  (130), and Karma,  $\alpha = 0.095$  (65)

(260)	Nichr.*	Excello	(260)	Nichr.*	Excello
$t$	$\alpha$	$\alpha$	$t$	$\alpha$	$\alpha$
25	0.32	0.22	575		0.15
50	0.30	0.23	600	0.05	0.11
100	0.30	0.26	650	0.05	0.09
150	0.38	0.29	700	0.06	0.11
200	0.46	0.29	750	0.07	0.13
250	0.50	0.27	800	0.07	0.15
300	0.56	0.21	850	0.08	0.17
325	0.43		900	0.10	0.22
350	0.38	0.22	950	0.14	0.26
400	0.30	0.24	1000	0.18	0.29
450	0.24	0.25	1050	0.28	0.32
500	0.24	0.26	1075	0.36	
550	0.12	0.20			

\* At  $20^\circ\text{C}$ ,  $\alpha = 0.43$  (135); 20 to  $50^\circ\text{C}$ ,  $\alpha = 0.026$  (175); 20 to  $100^\circ\text{C}$ ,  $\alpha = 0.2$  (65)



## Ni-Cr-(Fe, Mn).—Continued

Co	Calido (65)	ChP	Chromel P (130)
Ce	Calorite	Eo	Excello (40, 260)
	Chromel A, v. Nichrome IV		Karma, v. Nichrome IV
			Rayo, v. Nichrome III
ChC	Chromel C (130)	Tt	Tophet

	Cr	Fe	Mn	$\rho$	$\alpha$
Co	8-16	24-25	(?)	110	0.12
ChP	10	0	0	70.6	0.54
Tt	10	26	3	107	
ChC	11	25	0	109	0.18
Ce	12	15	8	110	
Eo	14	0.5	0.5	92	0.16

## Ni-Cu; v. Ni-Cu-Zn and Cu-Ni

## Ni-Cu-Co; v. Ni

## Ni-Cu-Cr; v. Cu-Ni-Cr

## Ni-Cu-Fe-Mn-(Si, C), Monel metals; v. Cu-Ni-Fe-Mn-(Si, C)

## Ni-Cu-Mn; v. Cu-Ni-Mn

## Ni-Cu-Mn-Fe; v. Cu-Ni-Fe-Mn

## Ni-Cu-Ti; v. Cu-Ni-Ti

## Ni-Cu-Zn (281); cf. Cu-Ni-Zn

Cu	Zn	$\rho_{20}$
0	0	11.9*
0	11.0	23.8
0	14.3	28.4
0	21.8	36.4
0	29.2	42.3
5.4	0	31.1
3.2	11.0	31.7
4.2	22.8	42.3
5.2	31.2	55.5
4.2	32.2	56.2
7.3	21.7	73.4
10.8	0	64.1
10.5	10.3	62.8
10.5	13.1	103.1
10.4	31.0	128.3
17.0	0	121.7
14.8	7.7	126.9
13.6	19.4	126.9
27.5	0	179.2
25.2	7.6	177.8
24.2	11.4	177.2
22.0	11.9	180.5
19.7	24.6	177.2
32.2	10.8	248.6
44.7	7.5	304.0

\* Assumed as basis.

## Ni-Fe, v. Fe-Ni

## Ni-Fe-Cr; v. Fe-Ni-Cr, Ni-Cr-Fe, and Ni-Cr-(Fe, Mn)

## Ni-Fe-Mn; v. Fe-Ni-Mn

## Ni-Fe-Mn-Cu-(Si-C); v. also

Ni-Mn-Fe-Cu  
Alloy No. 141 (134); cf. (133)  
Fe, 28.86; Mn, 1.30; Cu, 0.16;  
Si, 0.13, C, 0.22

$l$	$\rho$
20	22.34
100	31.28
200	43.11
300	56.72
400	71.50
500	88.45
600	106.75
700	110.30
800	113.00
900	116.20
1000	119.05

## Ni-Mn-(Fe) (135); v. also Fe-Ni-Mn

Mn	$\rho$	$\alpha$
0	12.43	6.22
4.76	17.4	2.97
7.4	23.3	2.49
9.1	28.0	
11.1	36.4	
13.04	41.6	
16.67	51.2	
85	70.0*	1.3*

\* From (148);  $\alpha$  holds from 20 to 100°C.

Mn	$\rho_{20}$	$\alpha$	Lit.
0		5.56	(134)
0.249		4.60	(136)
0.626		4.52	(136)
0.99		3.57	(136)
5	19.96	1.0	(194)
4.2	17.4	2.97	(250)
7.4	23.3	2.49	(250)
1.5-2.0	13.95	3.6	(65)
4.2-5.0	21.6	3.6	(65)

All Alumel (130).  
MN Manganese nickel (65)  
Mno Magno (40, 65).

	Mn	Fe	$\rho$	$\alpha$
MN	1.5-5	(?)	15	
All	2.5	0.5	33.3	1.2
Mno	5	0	20.0	0.005

## Ni-Mn-Fe-Cu

Mn	Fe	Cu	$\rho_{20}$	$\alpha$	Lit.
0.1	0.65	0.25	10.63	5.37	(133)
2.1	0.9	0.4	13.95		(133)
4.75	0.75	0.2	19.43		(133)
0.59	0.14	0.03	9.12	4.90	(136)

## Ni-Ti (132, 188)

Ti	$\rho$	$\alpha$
2	24.7	1.9
2	30.3	1.72
5	53.5	0.77
10	66.6	

## Ni-Zn; v. Ni-Cu-Zn

## Pb-Ag; v. Ag-Pb

## Pb-Au (182)

Au	$\rho_t$	$l$
8.7	26.4	25.4
15.85	35.7	23.0
19.2	41.0	26.1
24.1	54.4	19.7
32.2	51.2	22.3
48.7	42.9	16.8

## Pb-Bi; v. Bi-Pb and Table 3

## Pb-Cd; v. Cd-Pb and Table 3

## Pb-In; v. In-Pb

## Pb-K; v. Table 3

## Pb-Mg; v. Mg-Pb

## Pb-Na; v. Table 3

Pb-Sb (182); v. also Table 3  
For Ag,  $\rho_0 = 1.54$ 

Sb	$\rho_t$	$l$
2.31	21.7	23.7
5.63	23.2	25.5
10.56	25.55	25.4
16.45	27.9	26.1
23.05	32.6	24.1
37.1	39.2	23.4
54.1	46.5	26.3
70.3	53.9	24.2

Pb-Sn (182, 188, 189); v. also  
Table 3  
For Ag,  $\rho_0 = 1.54$ 

Sn	$\rho_t$	$l$
8.5	18.94	18.6
12.4	18.59	9.1
22.8	17.68	16.0
35.9*	16.57	15.0
52.8	15.17	15.9
69.1	14.56	16.2
77.0†	14.28	18.6

\*  $\rho_0 = 14.77$ ;  $\alpha_0 = 3.78$ ;  $\beta_0 = 5.91$  (189).†  $\rho_0 = 12.31$ ;  $\alpha_0 = 3.886$ ;  $\beta_0 = 6.41$  (189).

## Pb-Tl (103)

Tl	$\rho_0$	$\alpha_0$	$\beta_0$
0	16.6	4.27	1.512
3.45	19.15	3.67	1.362
4.5	19.26	3.62	1.474
7	20.8	3.32	1.500
14	26.8	2.51	1.086
22	33.35	1.942	1.030
32	37.8	1.655	1.08
42	40.1	1.523	1.095
54	39.2	1.499	1.025
63	36.6	1.526	1.14
67	34.2	1.629	1.263
70	31.9	1.707	1.445
75	28.3	1.884	1.67
77.5	25.7	2.14	1.75
80*	23.8	2.30	1.78
85*	20.8	2.68	2.38
89.9*	19.2	2.96	3.11
90.0*	18.9	3.03	3.34
93.5*	19.04	3.00	3.53
95.0*	18.13	3.19	3.92
96.5*	16.81	3.41	3.86
98.0*	15.50	3.68	3.81
99.5*	14.23	4.02	3.42
100.0*	13.80	4.16	2.30

\*  $\beta$ -form.



Pb-Tl.—(Continued)

Tl (158)	$\rho_{25}$	$\alpha^*$	Tl (158)	$\rho_{25}$	$\alpha^*$
0	21.50	4.24	79.76	23.86	2.78
4.85	24.52	3.67	89.86	20.09	3.40
9.8	27.37	2.97	92.89	19.63	3.75
24.7	33.52	2.23	94.93	19.59	3.71
39.60	37.48	1.98	95.43	20.40	3.97
49.61	38.31	1.78	96.45	21.52	3.55
59.63	36.95	1.72	96.95	22.90	4.27
66.33	34.11	1.85	97.97	20.76	4.04
69.67	31.79	1.91	98.99	19.43	4.42
74.72	28.12	2.19	100	18.25	4.78

\* 25 to 100°C.

Pb-Zn; v. Table 3

Pd-Ag, Pd-Au, Pd-Pt; v. Ag-Pd, Au-Pd, Pt-Pd

Pt-Ag; v. Ag-Pt

Pt-Ir (140)

Ir	$\rho_{25}$	$\alpha^*$
1	12.51	3.23
2.5	14.66	2.61
5	18.23	2.03
10	24.39	1.38

\* 25 to 100°C.

Ir	$\rho_0$	$\alpha^*$ (81)
0	10.07	3.48
5	17.82	1.88
10	23.05	1.26
15	26.9	1.02
20	29.5	0.81
25†	31.55	0.66
30	32.9	0.58
35	36.9	0.58
(10)		
0	9.766	3.940
10	25.397	1.150
15	28.650	0.928
20	33.16	0.739
100	8.19	2.93
19.9	30.90†	0.822†

\* 0 to 160°C.

†  $\Delta H = 0.5$  if  $t_A = 950^\circ\text{C}$  (112).

‡ From (74); Pt-Ir.

20% Ir (63); cf. (62)

$t^*$	$\rho_t$
-197.1	26.031
-106.1	28.347
-81.9	28.836
0	30.896
+1.8	30.933
16.1	31.296†
93.3	33.271

\* Pt scale of  $t$ . †  $\alpha_{15} = 0.822$ .

Ir	$\alpha$	$\beta$	Lit.
6	1.453	-1.576	(173)
10	1.177	-0.1086	(173)
10	1.5		(144)
15	0.782	-0.02106	(173)
20	1.048	-0.3683	(173)

Pt-Pd (140)

Pd	$\rho_{25}$	$\alpha$
1	11.98	3.38
2.5	13.47	2.94
5	15.61	2.46
10	19.50	1.80

Pd (81)	$\rho_0$	$\alpha^*$
0	10.06	3.48
10	18.6	1.36
20	23.38	1.18
30	25.65	1.00
40	26.45	0.96
50	25.72	1.03
60	24.26	1.04
70	21.87	1.28
80	18.92	1.55
90	14.43	2.14
100	10.58	3.28

\* 0 to 160°C.

Pt-Rh (140)

Rh	$\rho_{25}$	$\alpha$
1	12.56	3.26
2.5	14.34	2.71
5	16.77	2.17
10	21.853	1.47

Rh	$\rho_0$	$\alpha$	Lit.
10	22.45	1.35	(10)
10	21.1	1.7	(144)
9.1		0.350	(162)
10	21.14	1.43	(76)

10% Rh (63); cf. (62)

$t^*$	$\rho_t$
-197.1	15.134
-106.1	18.065
-81.9	18.648
0	21.142
+1.75	21.188
16.15	21.635†
92.25	23.943

\* Pt scale of  $t$ . †  $\alpha_{15} = 1.43$ .

Rb-K; v. K-Rb

Sb-Cd, Sb-Cu, Sb-Pb; v. Cd-Sb, Cu-Sb, Pb-Sb

Sb-Se (215), 45.2% Se	Treatment	$\rho_{17}$
Q in $\text{H}_2\text{O}$ .....		56 000
Q in air.....		11 300
A.....		9 400

Sb-Se.—(Cont'd)

47.5% Se =  $\text{Sb}_2\text{Se}_7$ 

First cycle

$t$	$\rho_t$	$t$	$\rho_t$
15	198 000	382	319 000
124	225 000	339	346 000
182	243 000	317	351 000
313	292 000	246	346 000
360	301 000	157	297 000
414	279 000	15	221 000
440	265 000		

After 10 cycles

$t$	$\rho_t$
15	887 000
161	864 000
385	584 000
440	376 000
49.3 Se = $\text{Sb}_2\text{Se}_3$	
$t$	$\rho_t$
23	$2010 \times 10^6$
50	$555 \times 10^6$
110	$59 \times 10^6$
518	$0.9 \times 10^6$

Sb-Sn, Sb-Te; v. Sn-Sb, Te-Sb

Sb-Zn (180)

For Ag,  $\rho_0 = 1.54$ 

Zn	$\rho_{25}$
33.33	373

Si-Fe-Al (33)

Fe	Al	$\rho_{12}$
3.78	0.43	470 000
14.42	0.42	240 000
8.67	0.65	154 000
11.35	0.53	118 000
6.67	1.02	82 000
11.16	1.25	95 000

Sn-Ag, Sn-Al, Sn-Au, Sn-Bi; v. Ag-Sn, Al-Sn, Au-Sn, Bi-Sn

Sn-Cd, Sn-Cu, Sn-Hg; v. Cd-Sn, Cu-Sn, Hg-Sn

Sn-K; v. Table 3

Sn-Mg; v. Mg-Sn

Sn-Na; v. Table 3

Sn-Pb; v. Pb-Sn

Sn-Sb; v. also Table 3

Sb (151)	$\rho_{25}$	$\alpha$
0	10.39	3.85
1	11.91	
4	14.1	
6	14.88	3
8	15.48	
10	17.61	2.72
12	17.67	
20	19.68	3.11
30	22.94	3.25
35	23.26	3.48
39.27	25.38	3.53
41	24.04	3.61

Sn-Sb.—(Cont'd)

Sb (151)	$\rho_{25}$	$\alpha$
43	26.52	
43.5	29.07	3.44
44	29.67	3.40
46	31.25	2.82
49	30.0	2.91
50	28.57	3.43
51	29.76	
52	32.26	2.77
53	31.95	
54	32.26	
56	32.57	2.62
58	34.48	2.25
60	38.02	1.81
67	39.22	
70	43.47	
75	46.73	1.69
80	49.5	1.63
90	54.64	1.62
95	50.76	3.90
100	43.67	5.03

For Ag,  $\rho_0 = 1.54$  (182)

Sb	$\rho_t$	$t$
1.04	15.43	27.9
2.06	16.02	25.7
5.01	18.14	27.0
9.55	20.0	27.4
17.4	21.36	22.4
26.0	22.48	20.4
34.04	25.37	20.7

Sn-Te (119)

Te	$\rho_{18}$
10	15.23
20	32.45
30	48.5
40	68.5
50	97.1
48.1*	103
55	145
60	204
65	238
70	322.8
80	1491
90	2780

\* TeSn.

Sn-Zn; v. also Table 3

For Ag,  $\rho_0 = 1.54$  (182, 188, 189)

Zn	$\rho_t$	$t$
8.5	12.16	21.3
12.3	11.56	20.0
21.9	10.07*	20.0
36.0	8.88	19.9
52.9	7.83	21.1
69.2	6.91	20.1

\*  $\rho_0 = 9.12$ ;  $\alpha = 3.884$ ;  $\beta = 6.86$  (189).



Te-Ag* (230)			Te-Sb (119)	
<i>t</i>	$\rho_t$ †	$\rho_A$ †	Sb	$\rho_A$
2 % Ag			5	2000
330	17.6	17.6	10	1820
280	22.9	22.9	20	1136
230	31	31	25	625
185	41.6	43.6	30	500
129.5	28.6	72.4	35	345
75	23.1	131.6	38.9*	208.3
+21	18.3	182.7	40	263.2
-30		156	50	286
-94		118.5	60	345
4 % Ag			70	435
330	18.2	18.2	80	526
260	28	28	* Te <sub>3</sub> Sb <sub>2</sub>	
200	41.9	41.7	Te-Sn; v. Sn-Te	
179	50	50.5	Tl-Bi; v. Bi-Tl	
120.5	33.3	94	Tl-Cd (190)	
71	28.3	180	Cd	$\alpha_0$ $\beta_0$
+10		275	5	3.673 6.94
-7		271	Tl-Pb; v. Pb-Tl	
-15		278	Tl-Sn (190)	
-63		244	Sn	$\alpha_0$ $\beta_0$
20 % Ag			5	3.120 2.97
290	22.4	22.4	W-Fe, W-Mo; v. Fe-W, Mo-W	
230	38.3	38.3	Zn-Al, Zn-Cd, Zn-Cu, Zn-Mg,	
200	49.9	49.0	Zn-Pb, Zn-Sn; v. Al-Zn,	
180	58.0	59.2	Cd-Zn, Cu-Zn, Mg-Zn,	
80	87	265	Pb-Zn, Sn-Zn	
+30	88	419		
-97	144	1520		

\* See also Tables Annuelles, 3: 264; 1912. Italic numbers are apparently maxima.

† Resistivity when cooled from melting point to *t*, rapidly ( $\rho_t$ ), slowly ( $\rho_A$ ).

#### Named alloys of unstated composition

<i>t</i>	$\rho_t$	$\alpha_0$	Range, °C
American nickel (3)			
25	72.92	5.16	25-200
200	138		
400	214	1.22	400-1000
700	269		
1000	319		
Beacon alloy			
60-80	0.7		
Extra Prima (66, 141)			
0	29.35	0.28	17
Ferrozoid (160)			
	84		
Ferry (160)			
	47.2		
Krupp (a Ni-steel) (135)			
20	85	0.70	20
Mangaloy (175)			
20	107	0.073	20-50
New Metal (141)			
0	51.1	-0.038	17
Resista			
	76	1.1	
Rheostene (a Ni-steel)			
	77	1.2	
Superior (46, 60, 141, 260)			
0	81.0	1.15	17
15	87.2	0.81	

Superior (260)		Superior.—(Cont'd)	
<i>t</i>	$\alpha$	<i>t</i>	$\alpha$
25	0.96	650	0.32
50	0.92	700	0.29
100	0.84	750	0.27
150	0.76	800	0.26
200	0.68	850	0.25
250	0.60	900	0.25
300	0.49	950	0.25
350	0.42	1000	0.24
400	0.41	1050	0.24
450	0.40	Tarnac (67, 160)	
500	0.39	<i>t</i>	$\rho_t$ $\alpha_0$ Range
550	0.38	(?)	41 0.025 20°
600	0.36		

TABLE 3.—RESISTIVITY OF NON-MERCURIC ALLOYS AT TEMPERATURES NEAR AND ABOVE THEIR NORMAL MELTING POINTS

The mercuric alloys Hg-K and Hg-Na for which data are available for a considerable range of *t*, are here included; for others, see Table 2.

When neither the initial nor the final temperature is the same for every member of a given system but  $\rho$  is recorded for some intermediate temperature that is common to every member, then that  $\rho$  and the corresponding temperature are printed in bold face; if two are required, the second is in italics.

Unit of  $\rho = 1$  microhm-cm =  $10^{-6}$  ohm-cm, of  $D = 0.01$  microhm-cm per 1°C; temperature is *t*, °C.

Al-Cu* (24)		Al-Cu.—(Cont'd)		Bi-Cd-Pb-Sn	
<i>t</i>	$\rho_t$	<i>t</i>	$\rho_t$	Wood's metal (283)	
0 % Cu		70 % Cu		Bi, 55.74; Cd, 16.80;	
700	27.80	800	65.44	Pb, 13.73; Sn, 13.3	
$D = +1.467$		$D = +0.096$		<i>t</i>	$\rho_t$
1300	36.68	1300	65.92	122.8	110.3
1100	33.68	1100	65.70	96.8	106.9
5 % Cu		77.72 % Cu		89.0	104.7
700	28.05	1000	72.30	85.0	101.6
$D = +1.723$		1100	70.27	77.4	95.0
1300	38.39	1200	68.47	74.7	93.25
1100	34.96	1300	66.95	69.8	88.8
19.67 % Cu		82 % Cu		65.2	66.4
600	30.87	1000	72.30	65.0	60.75
$D = +0.814$		1100	70.08	57.7	60.1
1300	36.57	1200	68.00	52.2	59.1
1100	34.95	1300	66.22	49.0	58.5
32.84 % Cu		85 % Cu		41.8	57.85
600	39.03	1100	66.72	33.0	56.4
$D = +1.386$		87.7 % Cu		17.8	54.4
1300	48.73	1400	63.57	9.8	52.6
1100	45.97	1100	62.50	0.0	51.7
50 % Cu		90 % Cu		24.0	54.3
600	45.45	1100	58.22	34.2	55.3
$D = +0.554$		$D = -0.41$		45.7	56.9
1300	49.33	1300	57.40	50.3	57.7
1100	48.22	95 % Cu		57.1	58.4
55 % Cu		1100	43.18	65.0	60.0
600	48.32	1200	43.33	67.3	60.2
$D = +0.263$		$D = +0.24$		68.7	60.4
1300	50.16	1400	43.81	70.2	61.0
1100	49.64	100 % Cu		71.4	62.6
		1100	21.52	73.0	63.95
		$D = 0.883$		74.5	87.4
		1400	24.17	75.0	88.7
				75.5	89.2

\* Values of  $\rho$  appear to be too high.



Bi-Cd-Pb-Sn.—  
(Cont'd)

$t$	$\rho_t$
76.4	91.9
77.4	93.65
78.5	95.2
86.2	102.2
88.0	102.85
96.5	105.5
98.5	106.5

## Bi-Pb-Sn

Rose's metal (283)  
Bi, 48.90; Pb, 27.54;  
Sn 23.55

$t$	$\rho_t$
129.8	92.25
122.5	91.7
117.5	91.3
109.8	90.8
104.1	90.25
97.2	90.1
95.2	89.8
93.5	88.15
93.4	86.75
92.6	85.75
91.0	76.15
85.0	72.9
78.2	72.3
71.7	72.0
64.7	71.4
61.1	71.1
50.2	70.25
42.8	69.5
38.0	69.1
33.7	68.3
31.1	68.2
28.0	68.0
22.7	67.1
16.7	66.7
7.4	65.4
0.0	64.4
10.0	65.6
20.0	66.9
35.9	68.8
42.7	69.8
48.4	70.4
59.0	70.5
69.2	72.6
85.7	75.06
89.9	76.1
93.5	77.9

Bi-Pb-Sn-Cd  
Lipowitz' alloy (283)

$t$	$\rho_t$
124.1	98.6
111.0	97.6
108.7	97.25
93.8	96.85
88.0	96.6
87.2	96.4
83.5	96.4
75.9	96.0
71.7	95.9
69.0	95.25

Bi-Pb-Sn-Cd.—  
(Cont'd)

$t$	$\rho_t$
69.0	93.5
68.2	91.4
68.0	74.7
67.0	66.0
66.5	62.3
66.0	62.15
61.2	61.9
57.1	61.4
53.1	61.0
50.5	60.65
45.0	60.2
38.0	59.6
33.8	53.8
26.8	57.66
24.0	56.04
23.0	55.5
22.0	55.3
15.0	54.32
+13.1	54.2
-4.0	51.9
-4.0	51.9
0.0	52.5
+7.8	53.3
10.1	53.6
23.2	55.1
33.0	56.4
39.7	57.3
44.0	57.9
50.8	58.9
56.0	59.6
60.0	60.2
66.0	61.0
72.2	63.0
72.8	64.8
73.5	65.5

CdCl<sub>2</sub>-Cd(6)

$t$	$0.001\rho_t$
0.0 % Cd	
580	532
$f^* = -77.5$	
$g^* = +12.5$	
700	457
2.11 % Cd	
580	537
$f^* = -81.7$	
$g^* = +13.9$	
700	459
4.51 % Cd	
580	545
$f^* = -85.0$	
$g^* = +13.9$	
700	463
7.38 % Cd	
580	558
$f^* = -95.0$	
$g^* = +16.7$	
700	468

$\frac{\rho_t - \rho_{580}}{1000} = \frac{f}{100}(t - 580) + \frac{g}{10000}(t - 580)^2$ ;  
for a second set of mixtures,  $\rho$ 's were 1 % to 2 % less than those here given.

## Cd-Pb; v. Pb-Cd

## Cu-Al; v. Al-Cu

$t$	$\rho_t$
Cu-Ni (23)	
19 % Ni	
$t_m = 1187$	
1187	53.7
1200	53.8
1250	54.4
1300	55.5
1350	57.2
1400	59.2
1450	62.6
1500	66.5
1550	70.0
50.8 % Ni	
$t_m = 1326$	
1326	93.0
1350	93.6
$D = 2.33$	
1650	100.6
1450	95.9
65.3 % Ni	
$t_m = 1358$	
1358	136.7
1400	138.5
$D = 4.35$	
1600	147.2
1450	140.6
86.6 % Ni	
$t_m = 1419$	
1419	120.0
1450	120.6
$D = 2.20$	
1650	125.0
Cu-Pb (24)	
0 % Pb	
1100	21.52
$D = 0.882$	
1500	25.05
1300	23.29
2 % Pb	
1100	24.00
$D = 1.103$	
1400	27.31
1300	26.20
2.95 % Pb	
1100	25.06
$D = 1.157$	
1400	28.53
1300	27.37
16.92 % Pb	
1100	42.13
$D = 0.948$	
1500	45.92
1300	44.04
35.98 % Pb	
1100	60.82
$D = 1.077$	
1400	64.05
1300	62.98
36.30 % Pb	
1200	64.29
$D = 0.990$	
1500	67.26
1300	65.31

## Cu-Pb.—(Cont'd)

$t$	$\rho_t$
39.40 % Pb	
1300	66.69
$D = 0.885$	
1500	68.46
88.90 % Pb	
1300	124.20
1400	127.08
90.95 % Pb	
1200	121.25
1300	124.08
1400	126.09
98.0 % Pb	
700	113.2
$D = 4.21$	
1400	142.7
1300	138.5
100 % Pb	
700	111.8
$D = 4.60$	
1200	134.8

## Cu-Sb (23)

$t$	$\rho_t$
2 % Sb	
$t_m = 1070^\circ$	
1070	29.00
1100	29.24
1150	29.97
1200	30.18
1250	30.62
1300	31.12
$D = +1.035$	
1500	33.19
16.8 % Sb	
$t_m = 885$	
885	84.00
900	84.09
$D = +0.505$	
1300	86.11
1000	84.59
23.6 % Sb	
$t_m = 815$	
815	104.50
850	104.29
900	103.99
950	103.64
1000	103.39
1050	103.21
1100	103.19
$D = 0.000$	
1200	103.19
33.3 % Sb	
$t_m = 639$	
639	140.01
700	139.18
750	138.46
800	137.79
850	137.10
900	136.40
950	135.63
$D = -2.05$	
1200	130.50
1000	134.60

## Cu-Sb.—(Cont'd)

$t$	$\rho_t$
40 % Sb	
$t_m = 682$	
682	152.20
700	151.70
750	150.3
800	148.97
850	147.90
900	146.90
950	146.14
1000	145.38
$D = -0.990$	
1200	143.40
50 % Sb	
$t_m = 655$	
655	147.00
700	146.64
750	146.26
800	145.90
850	145.71
900	145.64
950	145.63
1000	145.68
1050	145.82
1100	146.00
1150	146.39
1200	146.80
70 % Sb	
$t_m = 543$	
543	119.40
600	118.40
$D = +2.400$	
1200	132.78
1000	127.98
80 % Sb	
$t_m = 533$	
533	116.44
600	118.10
$D = +2.40$	
850	124.10
900	125.39
950	126.70
1000	128.10
1050	129.60
1100	131.16
1150	132.70
98.85 % Sb	
$t_m = 625$	
625	122.9
650	123.49
$D = 2.41$	
850	128.31
900	129.60
950	130.94
1000	132.36
1050	135.90

## Cu-Sn (24)

$t$	$\rho_t$
0 % Sn	
1100	21.52
$D = 8.82$	
1500	25.05
2 % Sn	
1100	25.51
$D = 1.020$	
1400	28.57

## Cu-Sn.—(Cont'd)

$t$	$\rho_t$
4.76 % Sn	
1100	32.71
$D = 0.920$	
1400	35.47
20.0 % Sn	
900	58.53
$D = 0.192$	
1300	59.30
1100	58.92
1400	59.47
1500	59.63
38.43 % Sn	
800	74.02
900	73.05
1000	72.50
1100	72.22
1200	72.08
1300	72.15
1400	72.32
1500	72.60
42.5 % Sn	
800	74.95
900	74.20
1000	73.75
1100	73.40
1200	73.40
1300	73.80
1400	73.95
60 % Sn	
700	67.40
$D = 1.033$	
1000	70.50
1100	71.75
1200	73.10
1300	74.50
1400	75.90
80 % Sn	
600	59.80
700	61.90
800	63.98
$D = 2.037$	
1400	76.20
1100	70.08
100 % Sn	
300	49.45
400	51.60
500	53.85
$D = 2.239$	
1500	76.24
1100	67.20
Cu-Zn (24)	
0 % Zn	
1100	21.52
$D = 0.885$	
1300	23.29
0.9 % Zn	
1100	22.03
$D = 1.000$	
1300	24.03
3.5 % Zn	
1100	23.13
$D = 1.100$	
1300	25.33



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Lambda_0$	<i>k</i> (or $\Delta_c$ )	Lit.
Formula	Name					
C <sub>11</sub> H <sub>12</sub> O <sub>3</sub>	Mesityleneglyoxylic acid.....	25	0.03–0.001	376	$\Lambda_{0.03} = 258$	(69, 105)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	Benzylsuccinic acid.....	25	0.016–0.002	375	$8.9 \times 10^{-5}$	(577)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	1-Monoethyl homophthalate.....	25	0.002–0.001	375	$4.5 \times 10^{-5}$	(540)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	2-Monoethyl homophthalate.....	25	0.004–0.001	375	$7.0 \times 10^{-5}$	(540)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	Mesitylenedicarboxylic acid.....	25	0.016–0.001	376	$9.6 \times 10^{-4}$	(105)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	Methylbenzylmalonic acid.....	25	0.016–0.0005	375	$2.6 \times 10^{-3}$	(524)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	<i>f u m.-s y m.</i> -Methylphenylsuccinic acid.....	25	0.02–0.0008	375	$3.64 \times 10^{-4}$	(631)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	<i>m a l.-s y m.</i> -Methylphenylsuccinic acid.....	25	0.02–0.0008	375	$2.25 \times 10^{-4}$	(631)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	Phenylglutaric acid.....	25	0.03–0.003	376	$7.62 \times 10^{-5}$	(567)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	$\alpha$ -Monomethyl phenylsuccinate...	25	0.002–0.0005	375	$4.8 \times 10^{-5}$	(602)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub>	$\beta$ -Monomethyl phenylsuccinate...	25	0.004–0.0005	375	$1.05 \times 10^{-4}$	(540, 602)
C <sub>11</sub> H <sub>12</sub> O <sub>4</sub> S <sub>2</sub>	Benzylidenebisthioglycolic acid...	25	0.008–0.002	376	$6 \times 10^{-4}$	(280)
C <sub>11</sub> H <sub>12</sub> O <sub>6</sub>	1-Monomethyl hemipinate.....	25	0.008–0.001	375	$1.26 \times 10^{-3}$	(436, 605)
C <sub>11</sub> H <sub>12</sub> O <sub>6</sub>	2-Monomethyl hemipinate.....	25	0.008–0.001	375	$1.60 \times 10^{-4}$	(436, 605)
C <sub>11</sub> H <sub>13</sub> NO <sub>3</sub>	$\alpha$ -Acetylanilinopropionic acid.....	25	0.008–0.001	375	$1.22 \times 10^{-4}$	(579)
C <sub>11</sub> H <sub>13</sub> NO <sub>3</sub>	Acetyl- <i>o</i> -tolylaminoacetic acid....	25	0.005–0.0006	375	$2.15 \times 10^{-4}$	(394, 579)
C <sub>11</sub> H <sub>13</sub> NO <sub>3</sub>	Acetyl- <i>p</i> -tolylaminoacetic acid....	25	0.005–0.0012	375	$2.15 \times 10^{-4}$	(579)
C <sub>11</sub> H <sub>13</sub> NO <sub>3</sub>	2-Methylbenzoylaminopropionic acid.....	25	0.002–0.0006	375	$1.63 \times 10^{-4}$	(200)
C <sub>11</sub> H <sub>13</sub> NO <sub>3</sub>	4-Methylbenzoylaminopropionic acid.....	25	0.002–0.0006	375	$1.67 \times 10^{-4}$	(200)
C <sub>11</sub> H <sub>13</sub> NO <sub>3</sub>	<i>o</i> -Tolylsuccinamic acid.....	25	0.016–0.001	376	$2.04 \times 10^{-5}$	(436)
C <sub>11</sub> H <sub>13</sub> NO <sub>3</sub>	<i>p</i> -Tolylsuccinamic acid.....	25	0.004–0.001	376	$1.89 \times 10^{-5}$	(436)
C <sub>11</sub> H <sub>13</sub> NO <sub>4</sub>	1-Monomethyl 2-dimethylamino-terephthalate.....	25	0.03–0.001	376	$[4 \times 10^{-6}]$	(601)
C <sub>11</sub> H <sub>13</sub> NO <sub>4</sub>	4-Monomethyl 2-dimethylamino-terephthalate.....	25	0.03–0.001	376	$[3 \times 10^{-7}]$	(601)
C <sub>11</sub> H <sub>13</sub> NO <sub>4</sub>	1-Monomethyl 4-dimethylaminoisophthalate.....	25	0.0025–0.0006	376	$5.5 \times 10^{-7}$	(601)
C <sub>11</sub> H <sub>13</sub> NO <sub>4</sub>	3-Monomethyl 4-dimethylaminoisophthalate.....	25	0.002–0.0005	376	$2.7 \times 10^{-5}$	(601)
C <sub>11</sub> H <sub>13</sub> NO <sub>4</sub>	$\beta$ -Monoethyl $\alpha$ , $\alpha'$ -dimethylcinchomerone.....	25	0.01–0.0012	375	$1.8 \times 10^{-5}$	(413)
C <sub>11</sub> H <sub>13</sub> NO <sub>4</sub>	$\gamma$ -Monoethyl $\alpha$ , $\alpha'$ -dimethylcinchomerone.....	25	0.01–0.0012	375	$2.1 \times 10^{-5}$	(413)
C <sub>11</sub> H <sub>13</sub> NO <sub>4</sub>	<i>o</i> -Tolyliminodiacetic acid.....	25	0.005–0.001	374	$2.0 \times 10^{-3}$	(579)
C <sub>11</sub> H <sub>13</sub> NO <sub>4</sub>	<i>p</i> -Tolyliminodiacetic acid.....	25	0.003–0.0015	374	$1.4 \times 10^{-3}$	(579)
C <sub>11</sub> H <sub>14</sub> O <sub>2</sub>	2, 3, 4, 5-Tetramethylbenzoic acid.	25	0.0005	375	$6 \times 10^{-5}$	(451)
C <sub>11</sub> H <sub>14</sub> O <sub>2</sub>	2, 3, 4, 6-Tetramethylbenzoic acid.	25	0.0005	375	$1 \times 10^{-4}$	(451)
C <sub>11</sub> H <sub>14</sub> O <sub>2</sub>	2, 3, 5, 6-Tetramethylbenzoic acid.	25	0.001–0.0005	375	$3 \times 10^{-4}$	(451)
C <sub>11</sub> H <sub>14</sub> O <sub>2</sub>	<i>p</i> -Thymotic aldehyde.....	25	0.0002–0.0001	375	$1 \times 10^{-4}$	(204)
C <sub>11</sub> H <sub>14</sub> O <sub>3</sub>	$\alpha$ -Ethyl- $\beta$ -phenyl- $\beta$ -hydroxypropionic acid.....	25	0.03–0.001	374	$3.04 \times 10^{-5}$	(550)
C <sub>11</sub> H <sub>14</sub> O <sub>3</sub>	Mesityleneglycolic acid.....	25	0.04–0.005	375	$2.1 \times 10^{-4}$	(69)
C <sub>11</sub> H <sub>14</sub> O <sub>3</sub>	$\alpha$ -Phenoxyisovaleric acid.....	25	(?)	(?)	$4.66 \times 10^{-4}$	(57)
C <sub>11</sub> H <sub>14</sub> O <sub>3</sub>	Phenylhydroxypivalic acid.....	25	0.03–0.001	374	$4.5 \times 10^{-5}$	(550)
C <sub>11</sub> H <sub>14</sub> O <sub>3</sub>	Phenylpropoxyacetic acid.....	25	0.04–0.0012	374	$4.9 \times 10^{-4}$	(195)
C <sub>11</sub> H <sub>14</sub> O <sub>4</sub>	3, 4-Diethoxybenzoic acid.....	25	0.001	375	$3.32 \times 10^{-5}$	(436)
C <sub>11</sub> H <sub>15</sub> NO <sub>2</sub>	$\alpha$ - <i>o</i> -Toluidinobutyric acid.....	25	0.005–0.0012	372	$5.2 \times 10^{-5}$	(579)
C <sub>11</sub> H <sub>15</sub> NO <sub>2</sub>	$\alpha$ - <i>p</i> -Toluidinobutyric acid.....	25	0.004–0.001	372	$1.02 \times 10^{-5}$	(579)
C <sub>11</sub> H <sub>15</sub> NO <sub>2</sub>	$\alpha$ - <i>o</i> -Toluidinoisobutyric acid.....	25	0.005–0.0012	372	$4.8 \times 10^{-6}$	(579)
C <sub>11</sub> H <sub>15</sub> NO <sub>2</sub>	$\beta$ - <i>o</i> -Toluidinoisobutyric acid.....	25	0.005–0.0012	372	$3.9 \times 10^{-6}$	(579)
C <sub>11</sub> H <sub>15</sub> NO <sub>2</sub>	$\alpha$ - <i>p</i> -Toluidinoisobutyric acid.....	25	0.005–0.0012	372	$6.6 \times 10^{-6}$	(579)
C <sub>11</sub> H <sub>15</sub> NO <sub>2</sub>	$\beta$ - <i>p</i> -Toluidinoisobutyric acid.....	25	0.005–0.0012	372	$4.0 \times 10^{-7}$	(579)
C <sub>11</sub> H <sub>15</sub> NO <sub>4</sub> S	Pseudocumenesulfoneaminoacetic acid.....	25	0.006–0.001	372	$2.44 \times 10^{-4}$	(358)
C <sub>11</sub> H <sub>15</sub> NO <sub>4</sub> S	<i>m</i> -Xylenesulfoneaminopropionic acid.....	25	0.008–0.001	372	$2.40 \times 10^{-4}$	(358)
C <sub>11</sub> H <sub>16</sub> O <sub>3</sub>	<i>d</i> -Camphorcarboxylic acid.....	25	0.016–0.001	375	$1.74 \times 10^{-4}$	(136, 436)
C <sub>11</sub> H <sub>16</sub> O <sub>3</sub>	<i>l</i> -Camphorcarboxylic acid.....	25	0.03–0.0012	375	$1.74 \times 10^{-4}$	(136)



Pb-Sn (23)		Pb-Sn.—(Cont'd)		Pb-Sn.—(Cont'd)		Pb-Sn.—(Cont'd)		Pb-Zn (150)		Pb-Zn.—(Cont'd)	
$t$	$\rho_t$	$t$	$\rho_t$	$t$	$\rho_t$	$t$	$\rho_t$	$t$	$\rho_t$	$t$	$\rho_t$
0.76% Sn		20% Sn		50% Sn		0.67% Sn		2% Zn		20% Zn	
$t_m = 324$		0   17.1		0   14.2		$t_s = 325$		0   18.8		$D = 7.39$	
324	94.10	$D = 8.34$		$D = 6.45$		325	93.0	$D = 8.63$		421	85.2
350	95.21	175	31.7	141	23.3	400	96.4	313	45.8	445	85.9
400	97.38	180	32.3	168	25.3	$D = 4.52$		315	50.2	500	88.1
450	99.55	180	34.6	177	26.2	1000	123.5	315	63.8	550	90.0
500	101.80	180	36.4	182	27.0	1.83% Sn		317	72.8	605	92.4
550	104.10	195	37.7	182	36.4	$t_s = 321$		319	77.3	690	97.1
600	106.42	207	39.6	185	41.3	321	92.5	320	80.7	30% Zn	
650	108.75	211	40.0	195	49.0	400	96.0	322	84.0	17.6	19.9
96.76% Sn		230	42.0	205	52.0	$D = 4.45$		327	87.0	70	23.1
$t_m = 224$		248	46.5	211	54.0	1000	122.7	357	89.1	$D = 7.75$	
224	48.66	260	53.2	225	57.8	4.86% Sn		380	91.8	310	41.7
250	49.13	269	59.0	234	58.0	$t_s = 308.8$		429	94.1	315	42.3
300	50.48	274	64.5	239	58.6	308.8	90.7	480	96.4	316	44.5
350	51.69	293	73.3	$D = 2.74$		400	94.6	510	97.6	316	51.4
400	52.91	$D = 3.52$		403	63.1	$D = 4.23$		5% Zn		320	59.0
450	54.20	455	79.0	80% Sn		1000	120.0	0	18.5	330	70.6
500	55.50	30% Sn		$D = 6.39$		11.51% Sn		$D = 8.34$		340	71.5
550	56.80	0	15.3	169	22.9	$t_s = 287.5$		283	42.1	350	72.2
600	58.13	$D = 8.05$		180	24.0	287.5	82.3	315	60.2	360	73.5
650	59.42	174	29.3	182	25.3	300	82.8	316	79.2	390	75.2
98.35% Sn		178	29.5	182	26.2	$D = 3.99$		333	86.7	405	77.0
$t_m = 228$		183	33.0	183	34.1	1000	110.7	354	88.6	415	77.4
228	48.38	184	35.6	188	36.4	400	86.8	371	90.6	427	89.9
250	46.90	186	39.8	190	38.3	24.22% Sn		394	93.1	450	90.5
300	50.00	195	40.7	195	41.2	$t_s = 263.8$		419	94.9	471	91.3
350	51.14	208	42.4	200	49.0	263.8	73.2	438	95.8	510	92.3
400	52.30	225	45.9	205	51.4	300	74.4	462	96.4	50% Zn	
450	53.45	232	47.6	215	52.5	$D = 3.37$		488	97.4	0	13.9
500	54.68	248	54.5	$D = 2.82$		1000	98.0	521	98.5	$D = 6.27$	
550	56.00	253	57.7	364	56.7	400	77.8	10% Zn		295	32.4
600	57.50	256	62.0	90% Sn		40.08% Sn		0	18.7	305	33.3
650	59.08	261	65.0	$D = 5.35$		$t_s = 236.3$		$D = 7.16$		310	41.7
(150); cf. (285)*		273	67.2	165	20.8	236.3	65.8	289	39.4	313	46.4
5% Sn		289	67.5	174	21.2	300	67.5	310	41.6	315	50.1
0	19.6	$D = 3.37$		178	21.6	$D = 2.89$		315	56.3	315	52.9
$D = 8.40$		455	73.1	180	22.2	1000	87.7	315	73.4	316	52.9
288	43.8	40% Sn		180	24.8	400	70.3	330	75.0	322	56.8
294	44.4	0	14.6	184	26.0	89.47% Sn		352	76.4	330	57.6
299	45.7	$D = 6.30$		197	29.9	$t_s = 207.5$		368	77.7	355	59.3
306	50.9	135	23.1	206	35.4	207.5	48.0	393	79.6	410	63.7
307	54.6	140	24.0	215	45.8	300	50.4	410	80.8	414	68.2
312	75.9	156	25.1	217	49.4	400	52.8	415	85.5	422	72.3
315	82.4	164	25.8	$D = 2.93$		$D = 2.93$		422	86.1	452	73
317	85.3	175	27.1	$D = 2.77$		1000	70.4	441	86.6	70% Zn	
330	86.0	178	27.5	390	54.2	100% Sn		470	88.0	20	10.9
$D = 4.08$		179	30.2	0.0% Sn (197)		$t_s = 232$		545	91.4	100	14.2
455	91.1	179	41.7	$t_s = 327$		232	47.6	589	92.6	$D = 4.50$	
10% Sn		181	42.7	327		300	49.1	20% Zn		291	22.8
0	18.2	188	43.9	400		400	51.4	22.0	20.0	308	23.6
$D = 8.82$		199	46.5	$D = 4.62$		500	54.0	60.0	22.2	316	24.4
245	39.8	212	49.2	1000	125.7	$D = 2.92$		$D = 7.39$		319	26.7
256	41.2	218	52.5	0.66% Sn		1000	68.6	294	39.5	320	29.8
265	42.5	225	54.0	$t_s = 326$		* Relative values;		315	41.9	323	33.9
280	44.3	234	58.7	326		curves similar to those of		336	70.4	327	38.5
294	46.9	236	60.5	400		data (150) here given,		354	72.0	335	38.9
306	78.1	242	61.6	$D = 4.52$		but discontinuity on		372	72.8	353	39.7
325	80.5	247	61.9	1000	124.2	heating occurs near 180°		382	74.3	380	40.8
$D = 3.51$		$D = 3.14$				in all cases, and the		399	75.5	400	41.1
436	84.4	470	68.9			upper linear portion be-		415	76.2	416	42.1
						gins at 200 to 230°C.		415	83.8	416	48.4



Pb-Zn.—(Cont'd)		Pb-Zn.—(Cont'd)		Sn-K (23)	
<i>t</i>	$\rho_t$	<i>t</i>	$\rho_t$	<i>t</i>	$\rho_t$
70% Zn		3.40% Zn		0.16% K	
<i>D</i> = 4.50		<i>t</i> * = 515		<i>t<sub>m</sub></i> = 245	
429	52.5	515	97.5	245	49.02
445	53.0	<i>D</i> = 4.23		250	49.1
507	53.7	800	109.55	300	50.09
90% Zn		6.44% Zn		350	51.08
0		<i>t</i> * = 587		400	52.58
<i>D</i> = 2.99		587	99.1	450	54.18
308	15.3	<i>D</i> = 4.19		500	56.00
316	15.6	900	112.2	550	57.90
318	17.7	800	108.0	Sn-Na (23)	
320	20.0	7.41% Zn		0.14% Na	
325	20.4	<i>t</i> * = 602		<i>t<sub>m</sub></i> = 231	
351	20.9	602	97.0	231	47.61
375	22.0	<i>D</i> = 3.86		250	48.18
400	23.0	900	108.5	<i>D</i> = 3.03	
410	23.7	800	104.6	500	55.75
414	25.4	11.52% Zn		Sn-Pb; v. Pb-Sn	
416	30.8	<i>t</i> * = 647		Sn-Sb (23)	
416	35.4	647	97.7	1.22% Sb	
430	36.4	<i>D</i> = 3.83		<i>t<sub>m</sub></i> = 234	
450	36.4	900	107.4	234	48.16
468	36.4	800	103.5	250	46.10
498	36.4	17.68% Zn		300	49.88
0.00% Zn (197)		<i>t</i> * = 727		350	51.16
<i>t<sub>s</sub></i> = 327		727	90.2	400	52.40
327	94.6	<i>D</i> = 2.51		450	53.69
<i>D</i> = 4.62		900	94.55	500	54.95
1000	125.7	800	92.0	550	56.28
800	116.4	20.38% Zn		600	57.62
0.48% Zn		<i>t</i> * = 783		Sn-Zn (23)	
<i>t<sub>s</sub></i> = 335		783	87.7	0.55% Zn	
335	93.2	<i>D</i> = 2.48		<i>t<sub>m</sub></i> = 232	
<i>D</i> = 4.77		900	90.6	232	47.58
1000	124.9	800	88.1	250	48.02
800	115.5	100% Zn		<i>D</i> = 2.65	
1.44% Zn		<i>t<sub>s</sub></i> = 419		650	58.61
<i>t<sub>s</sub></i> = 400		419	35.30	0.95% Zn	
400	94.8	<i>D</i> = 0.105		<i>D</i> = 2.30	
<i>D</i> = 4.67		800	35.70	650	57.60
1000	122.8	* Temperature at		Zn-Cu; v. Cu-Zn	
800	113.5	which separation occurs.		Zn-Pb; v. Pb-Zn	
2.3% Zn		Sb-Cu; v. Cu-Sb			
<i>t</i> * = 437		Sn-Cu; v. Cu-Sn			
437	95.6				
<i>D</i> = 4.11					
800	110.5				

I. Effect of reheating; carbon steels (for analyses, see original papers); $t = 25^{\circ}\text{C}$ (49); cf. (48, 191)								
C	0.04	0.30	0.35	0.41	0.57	0.76	0.945	1.05
$t_Q$	908°	908°	908°	908°	908°	903°	903°	903°
$\rho_Q$	11.10	16.04	17.63	18.46	21.41	30.95	36.82	40.07
$t_{Dr}$	$\rho_{Dr}$							
100	10.93	15.65	17.16	17.76	19.84	25.72	28.82	30.62
205	10.74	14.78	16.37	16.76	17.69	22.15	23.08	23.83
309	10.67	13.91	15.28	15.61	15.97	19.67	19.77	19.87
388	10.73	13.68	15.05	15.11	15.58	18.94	18.94	18.97
495	10.73	13.27	14.85	14.88	15.11	18.32	18.28	18.42
599	10.73	12.88	14.49	14.59	14.75	17.16	17.19	17.86
696	10.66	12.74	14.41	14.55	14.65	16.50	16.50	17.29
800	10.70	13.13	14.55	14.58	15.05	17.43	17.29	17.46
$t = 20^{\circ}\text{C}$ (48); cf. (49)								
C*	0.94	1.04	2.71	$t = 20^{\circ}\text{C}$ (88)				
$t_Q$	892°	892°	892°	C†	1.29	1.29		
$\rho_Q$	35.95	41.92	52.59	$t_{Dr}$	800°	1150°		
$t_{Dr}$	$\rho_{Dr}$			$\rho_{Dr}$	29.68	45.35		
105	27.97	33.02	42.65	$t_A$	$\rho_A$			
195	22.40	25.73	32.49	100	27.45	43.61		
295	19.42	21.82	27.41	200	20.92	38.33		
400	18.37	20.62	26.17	300	18.47	26.38		
492	17.60	19.92	24.92	350	16.77	19.52		
600	16.35	19.60	24.21	400	16.96	18.97		
700	16.19	19.03	22.57	600	16.40	17.55		
800	17.23	19.08	20.82	700	16.40	17.25		
				925	16.40	17.25		
II. Variation with temperature of tempering and of quenching; carbon steels, 0.8% < C < 1.2%; $\rho_Q - \rho_{Q'} = 0.04(t_Q - 800)^{\circ}\text{C}$ if $800^{\circ} < t_Q < 1100^{\circ}$ ; $t_{Q'} = 800^{\circ}$ (50, 166, 191).								
$t_{Dr}$	710°	740°	810°	850°	950°	1000°	C	
$\rho_{Dr}/\rho_A$	1.0	1.3	2.1	2.2		2.2	0.84%	
$\rho_{Dr}/\rho_A$	1.0	1.3	1.6	2.1	3.0		1.13%	
Alloy steels, composition 1/100 %								
$t = 15^{\circ}$ (165, 166)					$\rho$ for $t_{Dr}$			
Key¶	Cr	Si	Mn	C	0°§	750°	850°	1100°
1	250	27	23	50	19.5	19.5	29.2	40.9
2	280	27	21	82	21.5	28.0		66.7
3	240	36	21	107	24	31.2	36.0	72.0
$t = 20^{\circ}$ (218)					800°	900°	950°	1050°
4	882†	25	0	10	50.82	49.20	52.71	52.71
5	1724	34	tr.	13	52.71	57.23	60.63	65.26
6	2742	42	tr.	8	57.45	57.45	57.94	59.50
7	1018	34	5	75	48.25	47.50	57.50	62.42
8	2934	22	0	31	66.30	66.43	68.31	67.50
$t = 20^{\circ}$ (218)					$\rho$ for $t_{Dr}$			
Key	Mn	Si	S	C	0°§	750°	850°	1000°
9	36	1	0.9	11	13.30	14.31		14.36
10	47	tr.	2.2	17	11.11	13.28		13.13
11	12	8	3.4	30	14.26	13.49	15.60	16.07
12	14	11	2.5	37	15.17	19.40		19.65
13	14	9	2.2	56	16.83	20.54		23.60
14	14	8	1.3	88	16.84	28.72	35.79¶	
15	10	4	0.9	108	16.62	26.35	36.28¶	38.05
16	20	12	2.7	130	20.08	31.32		48.88
17	48	27	3.8	204	25.12	40.16	46.87	54.70
(218)	Mo**	Si	S	C	800°	900°	950°	1050°
18	119	18	6.5	72	39.34		39.91	42.33
19	253	16	6.3	77	39.01	39.00		

TABLE 4.—EFFECT OF HEAT TREATMENT UPON RESISTIVITY OF STEELS

Certain commercial steels are indicated by "Key" numbers; Chrome 1 to 8, 30, 31; Martin Assailly 9, 10; Holtzer crucible 11, 12, 14, 15; Imphy crucible 13; Allevard electrical 16; Edgar Allen crucible 17; Molybdenum 18, 19; Tungsten 20 to 24, 32; Whitworth mild 25, 26; Manganese 27, 28; Silicon 29. Data for single temperatures have been placed in Table 2, *q.v.* Unit of  $\rho$  = 10<sup>-6</sup> ohm-cm; temperature = *t*, °C.



Key 20 to 32 follow next section—(Mo, Mn, Si, C) steels.  
S, 2.5; P, 1.6; As, 2.0; N, 0.4 ( $\frac{1}{100}\%$ );  $t = 16$  to  $20^\circ\text{C}$ ;  $t_D = 550^\circ\text{C}$   
after  $t_Q = 800^\circ\text{C}$  (268, 269)

Mo	Mn	Si	C	$\rho_{A0} \uparrow \uparrow$	$\rho_A$	$\rho_{TD}$	$\rho_{Q800} \uparrow \uparrow$	$\rho_{Q1200} \uparrow \uparrow$	$\rho_R$
103	22	5	20		13.48	14.22	16.00		14.18
105	23	9	45		14.77	16.86	21.00		17.40
102	27	12	87	17.46	18.55	20.25	36.3		21.00
110	25	12	122	18.65	19.54	21.15	39.53	45.31	23.10
218	22	6	25		13.55	17.93	16.5	18.96	18.66
218	27	8	44		14.97	19.47	20.1	24.82	20.66
219	26	8	88	15.85	16.13	20.10	33.44		22.90
211	24	7	121	17.76	18.47	20.80	38.52	48.66	24.80
254	21	12	136		20.13	22.40	41.5		31.30
411	24	4	19		14.95	19.12	16.82	23.66	20.22
401	29	4	49		14.89	19.52	19.54	34.04	24.60
400	23	5	87	15.15	15.53	19.88	26.95	36.42	25.70
402	23	4	106	16.18	16.92	19.78	36.03		27.10
801	22	5	14	23.48	23.70	25.25	25.23	32.73	25.83
817	27	6	36		15.32	18.79	17.2	34.03	19.00
811	25	8	45		14.38	19.06	17.5	37.38	28.00
785	23	4	78	15.28	15.38	19.92	22.07	46.07	27.40
792	23	8	113	16.85	16.13	19.50	36.2	55.57	22.60

For Fe-Mo-Si-S-C, v. Key 18, 19.

$t = 15^\circ$ (165, 166)					$\rho$ for $t_D$			
Key	W	Mn	Si	C	$0^\circ\text{C}$	$750^\circ$	$850^\circ$	$1100^\circ$
20	270	44	30	76	18.5	27.8	31.4	35.2
21	270	38	32	111	20.0	26	28	44
22	290	40	20	55	18	21.6		32.4
23	500	30	2	60	21	21	31.5	37.8
$t = 20^\circ$ (218)					$800^\circ$	$900^\circ$	$950^\circ$	
24	1354	0	13	6	18.48	19.05	21.07	

### III. Effect of forging and hardening in oil ( $128^\circ$ ); $t = 0^\circ\text{C}$

Key	C	Mn	Si	Cr	W	P	$\rho_F$	$\rho_A$	$\rho_H$
25	32	44	4			4		14.46	13.90
26	89	16	8			2		15.59	16.95
27	67	473	61			8	53.68	39.28	55.56
28	130	874	9			7	69.93	63.16	70.66
29	68	69	344			13	61.63	61.85	61.95
30	53	39	22	62		4	20.16	19.42	27.08
31	69	3	13	120		4	17.91	18.49	30.35
32	136	4	4		465	5	22.49	22.50	22.74

\* For C < 0.04, data from (48) agree well with those given above for (49).

† Contains also: 0.07Mn, 0.15Si, 0.006P, tr. S.

‡ In this case, S = 0.11%, P = 0.11%; in all other specimens of (218) they are less.

§  $t_D = 0$  indicates value before tempering.

¶ Key indicates type of steel: 1 to 8, 30, 31 = Chrome; 9, 10 = Martin Assailly; 11, 12, 14, 15 = Holtzer crucible; 13 = Imphy crucible; 16 = Allevard Electrical; 17 = Edgar Allen crucible; 18, 19 = Molybdenum; 20 to 24, 32 = Tungsten; 25, 26 = Whitworth mild; 27, 28 = Manganese; 29 = Silicon.

¶  $t_D = 900^\circ$ .

\*\* For Fe-Mo-Mn-Si-C, v. below.

††  $\rho_{Q800} = \rho_Q$  when  $t_Q = 800^\circ$  ( $1200^\circ$ ).

‡‡ Carbide annealed. Drastic annealing for carbide analysis, kept at  $950^\circ\text{C}$  for 10 hr and cooled over 55 hr.

### TABLE 5.—ADDITIONAL REFERENCES

The papers here listed cannot be readily abstracted. Except for the named alloys, the papers are listed solely with reference to the individual metals contained in the alloys studied.

Ag (36, 57, 94, 95, 96, 156, 181, 183, 185, 231, 251)	Au (94, 95, 96, 100, 156, 181, 183, 185, 231, 251)
Al (8, 36, 37, 94, 205, 214, 266, 296)	Bi (7, 94, 96, 168, 247)
As (79, 228)	C (94, 115)
	Cd (251, 287)

Co (94, 227)  
Cr (94, 120)  
Cu (8, 39, 43, 59, 79, 94, 96, 99, 100, 143, 145, 156, 185, 214, 227, 228, 231, 251, 257, 286)  
Fe (8, 25, 26, 70, 94, 100, 108, 114, 115, 116, 214, 274, 278, 302); v. also Mn-steel, Ni-steel, Steel  
Hg (22, 197); v. also Amalgams  
Ir (94, 185)  
K (22, 197)  
Mg (36, 205)  
Mn (94, 100)  
Na (22, 197)  
Ni (8, 44, 59, 77, 94, 120, 145, 156, 214, 251, 274, 302)  
P (228)  
Pb (7, 22, 94, 100, 168, 197, 231, 247)  
Pd (94, 96, 149)  
Pt (57, 94, 96, 185)  
Rh (94)  
Sb (94, 96, 99, 143)  
Si (116)  
Sn (7, 39, 94, 96, 156, 231, 247)  
Ti (100)  
W (94)  
Zn (22, 39, 94, 96, 157, 197, 247, 251, 266, 286)

Amalgams (18, 60, 89, 92, 253, 292)  
Brass (204, 256)  
Chromel (32)  
Comet (32)  
Constantan (17, 272)  
German silver (214)  
Manganin (2, 17, 32, 171, 196, 233, 234, 255, 289, 291)  
Mn-steel (164)  
Monel (207)  
Nichrome (259)  
Ni-steel (42, 106, 107)  
Steel (5, 11, 15, 16, 28, 29, 42, 53, 78, 106, 107, 109, 115, 163, 164, 206, 213, 248, 256, 274, 278)  
Therlo (32)  
Low melting point alloys (56)  
Telegraph wire (290)  
Resistance at low temperatures (62, 63)  
Temperature coefficients (261)  
Effect of stress (32, 256, 271, 272)  
Theoretical (41, 61, 97, 98, 101, 157, 177, 213, 243, 244, 257, 263, 275, 294)  
Miscellaneous (62, 63, 74, 181, 188, 201, 256, 270)  
Bibliographies (35, 94, 239)

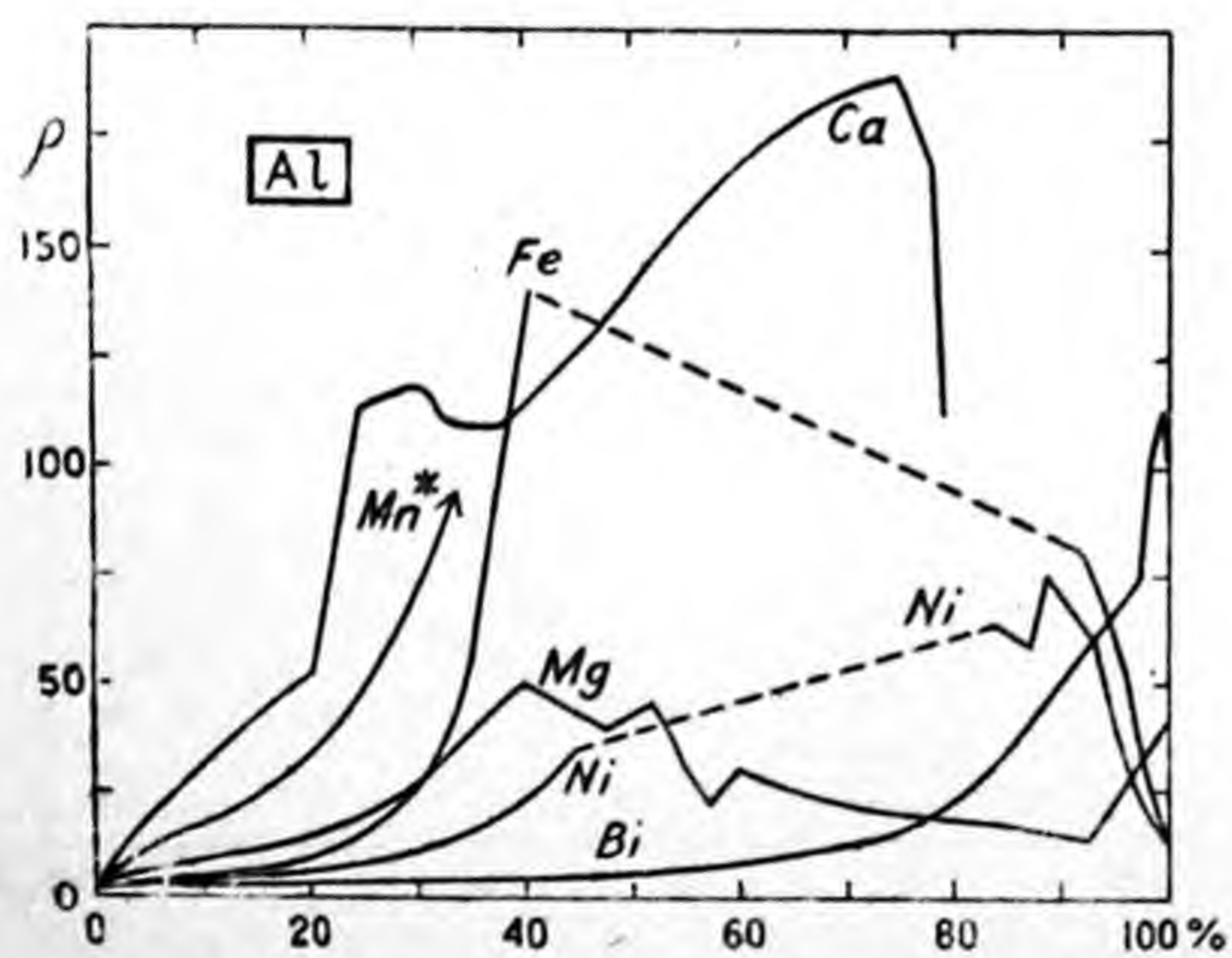
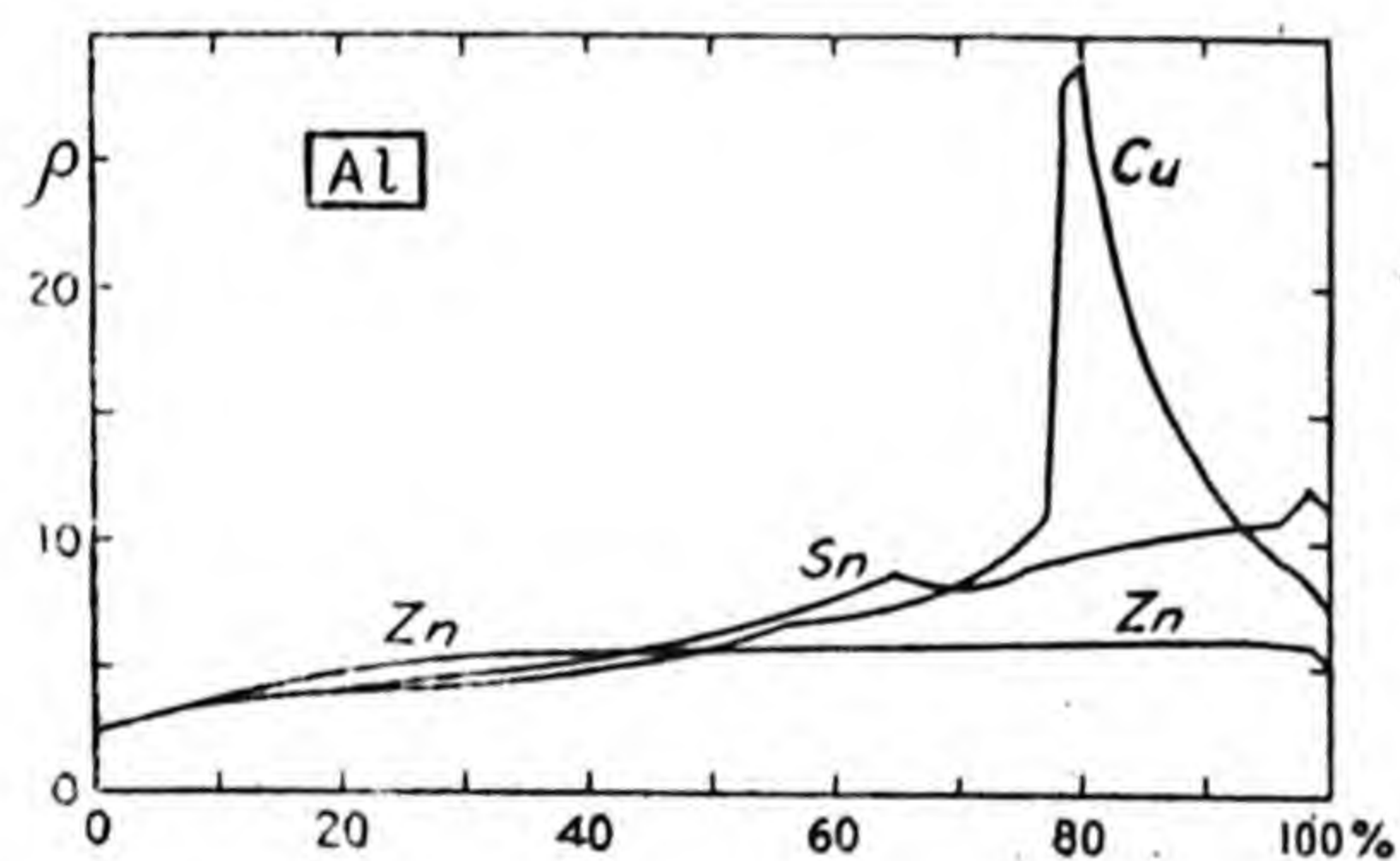
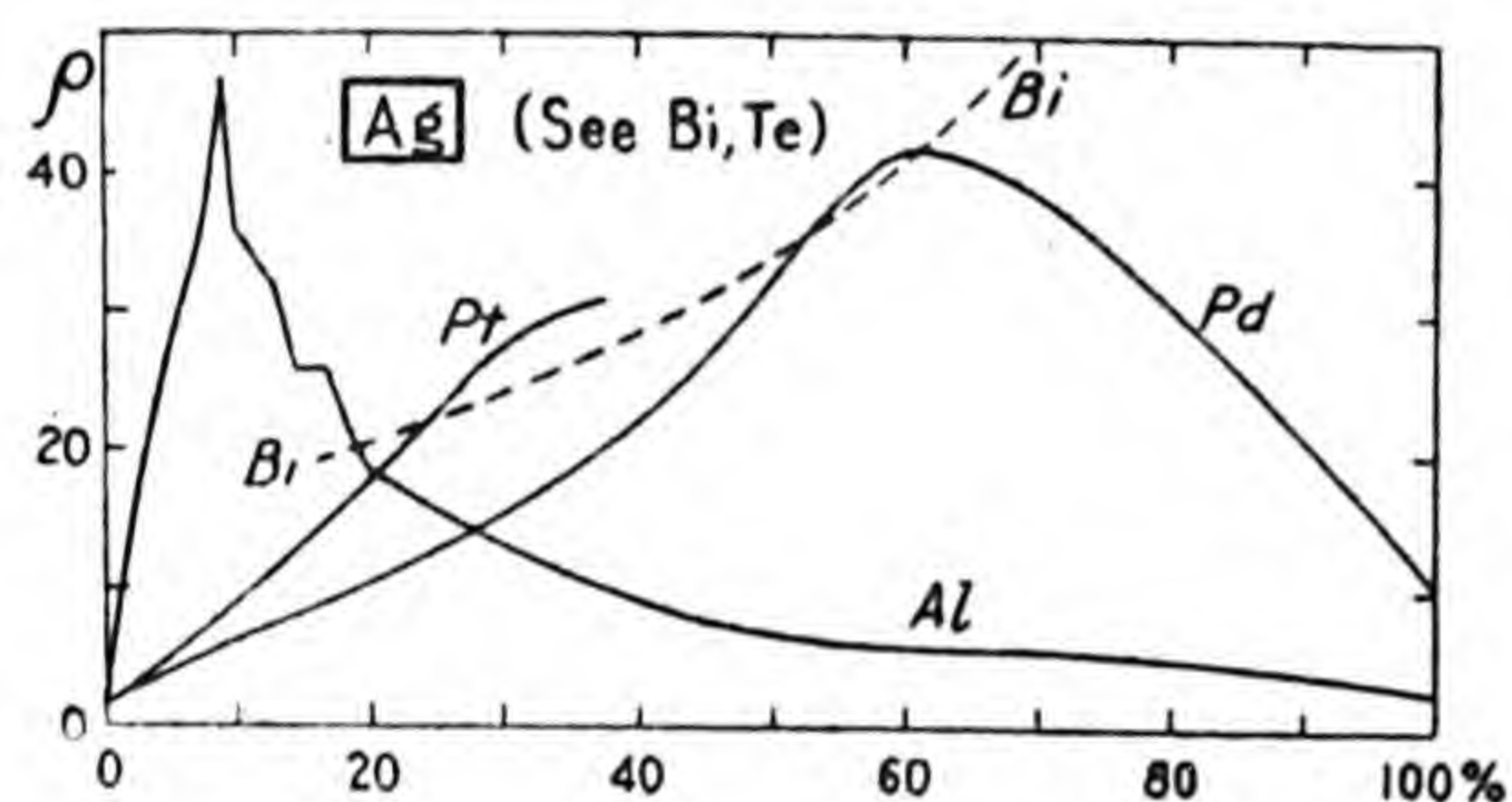
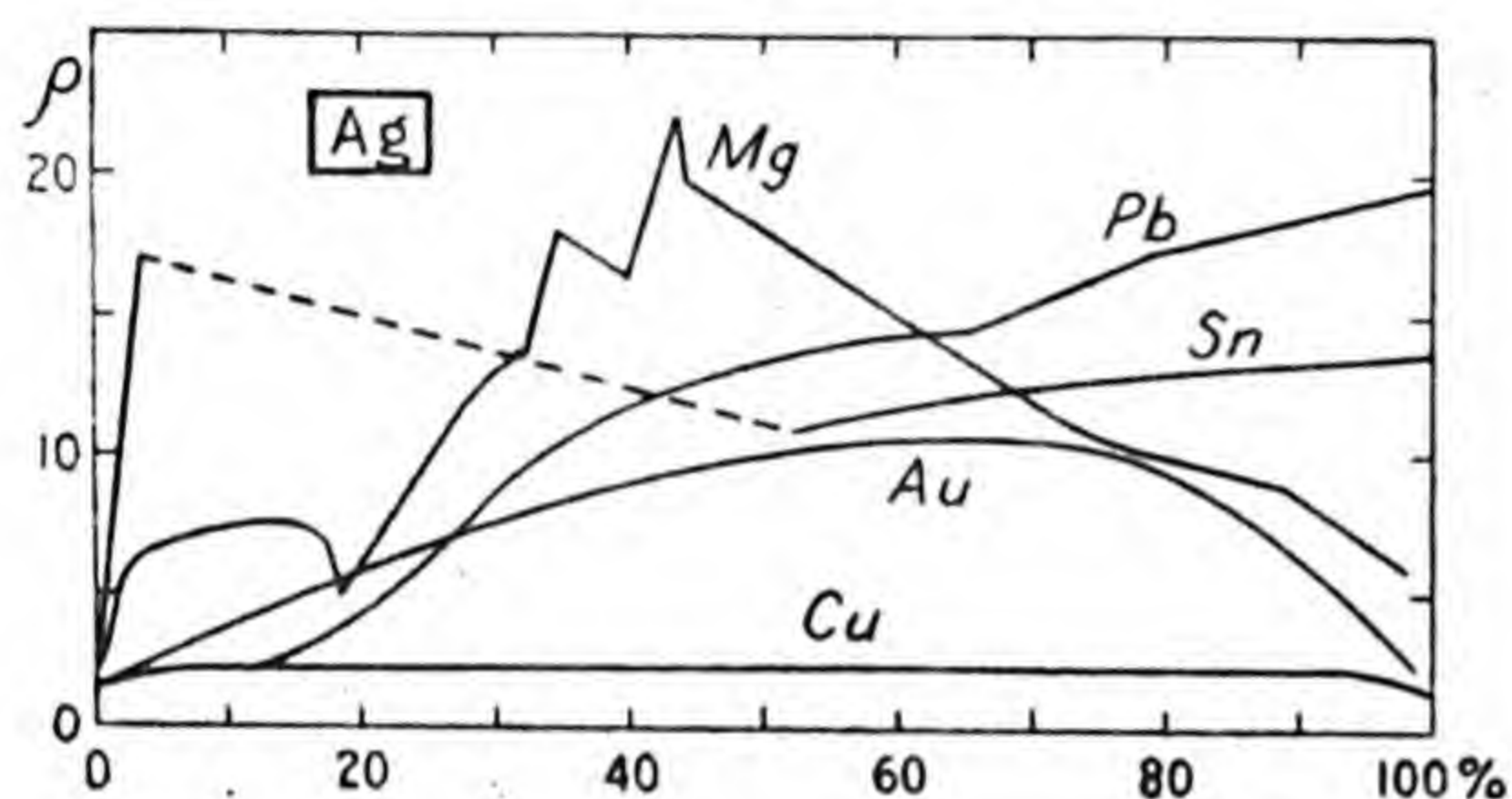
### LITERATURE

(For a key to the periodicals see end of volume)

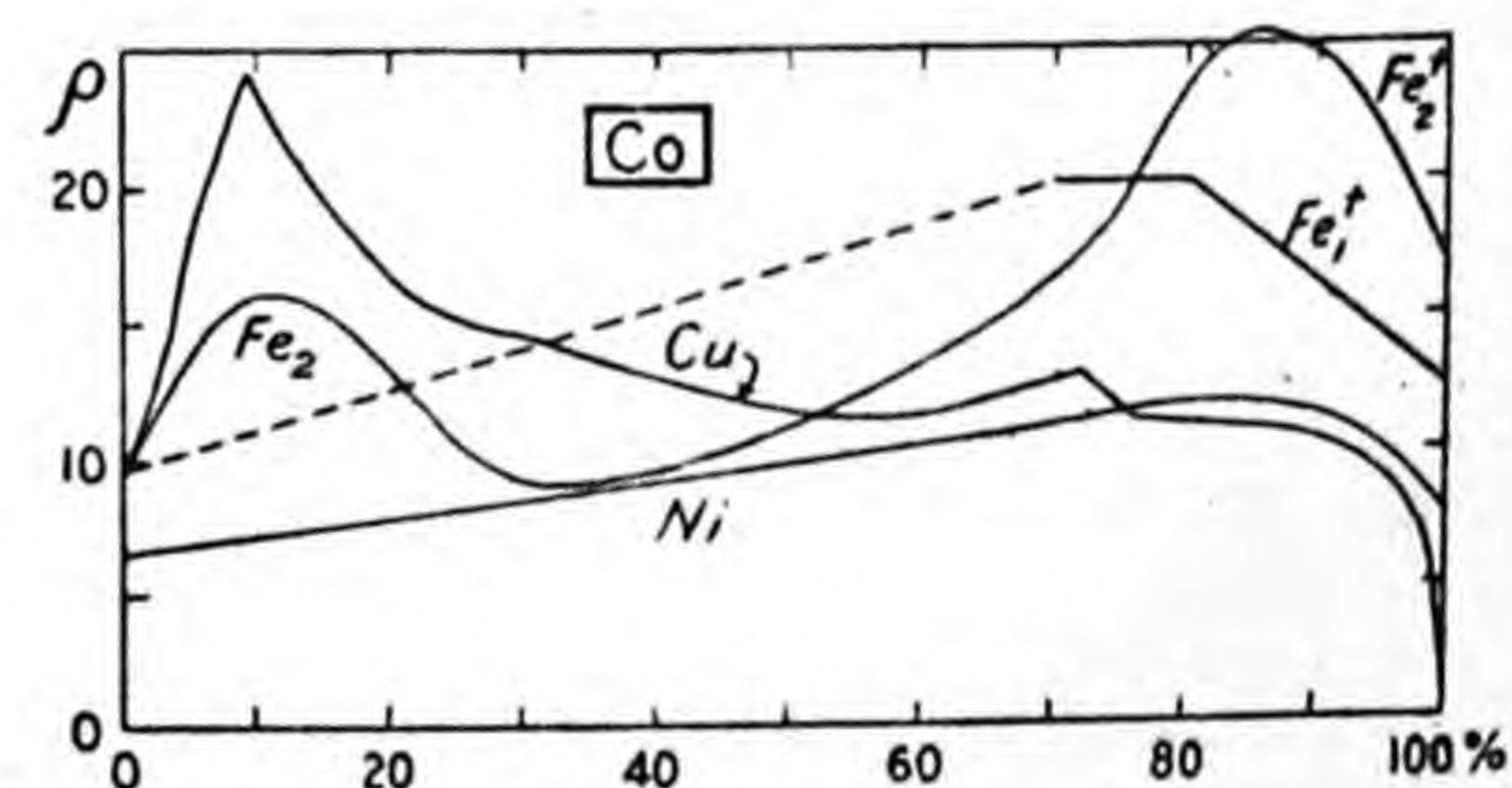
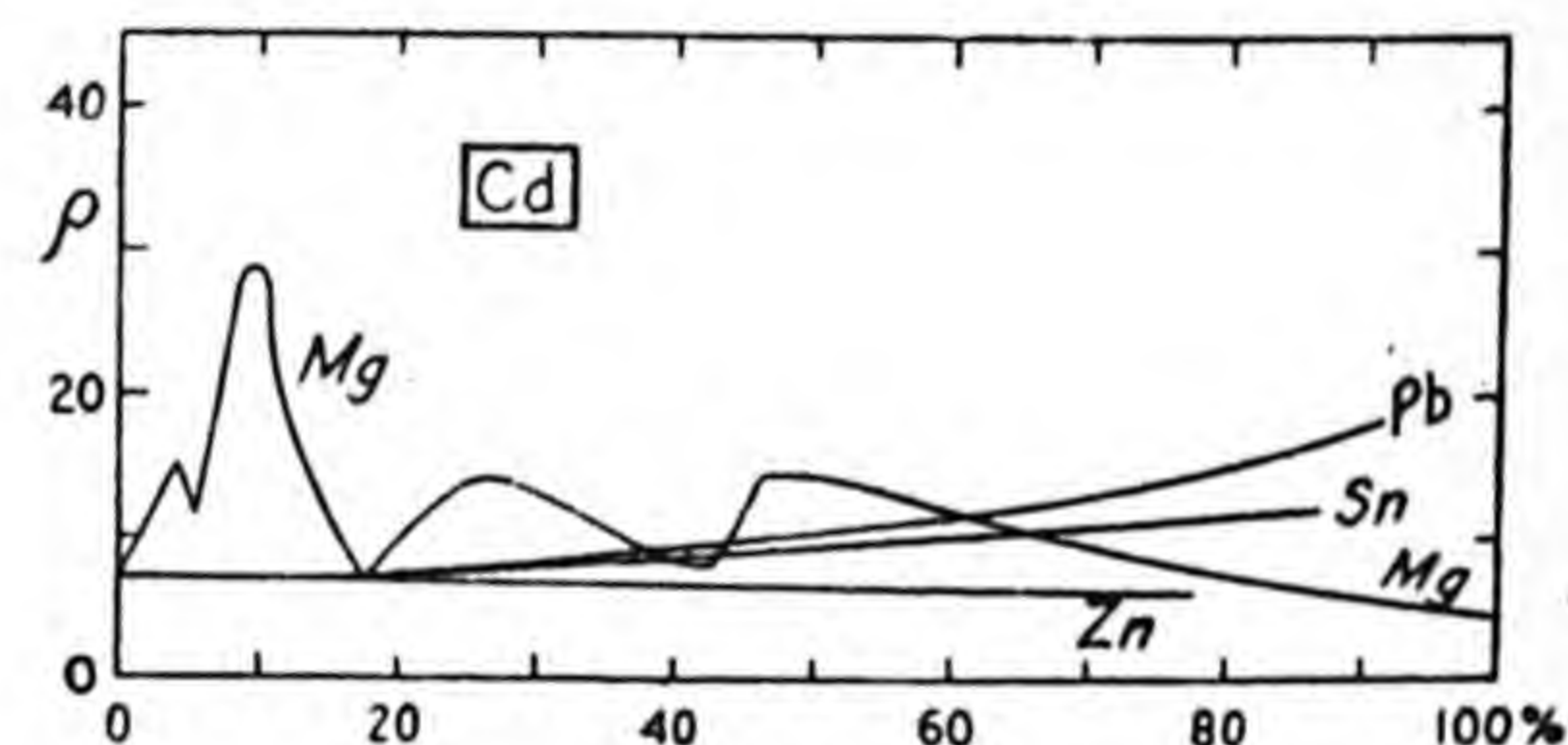
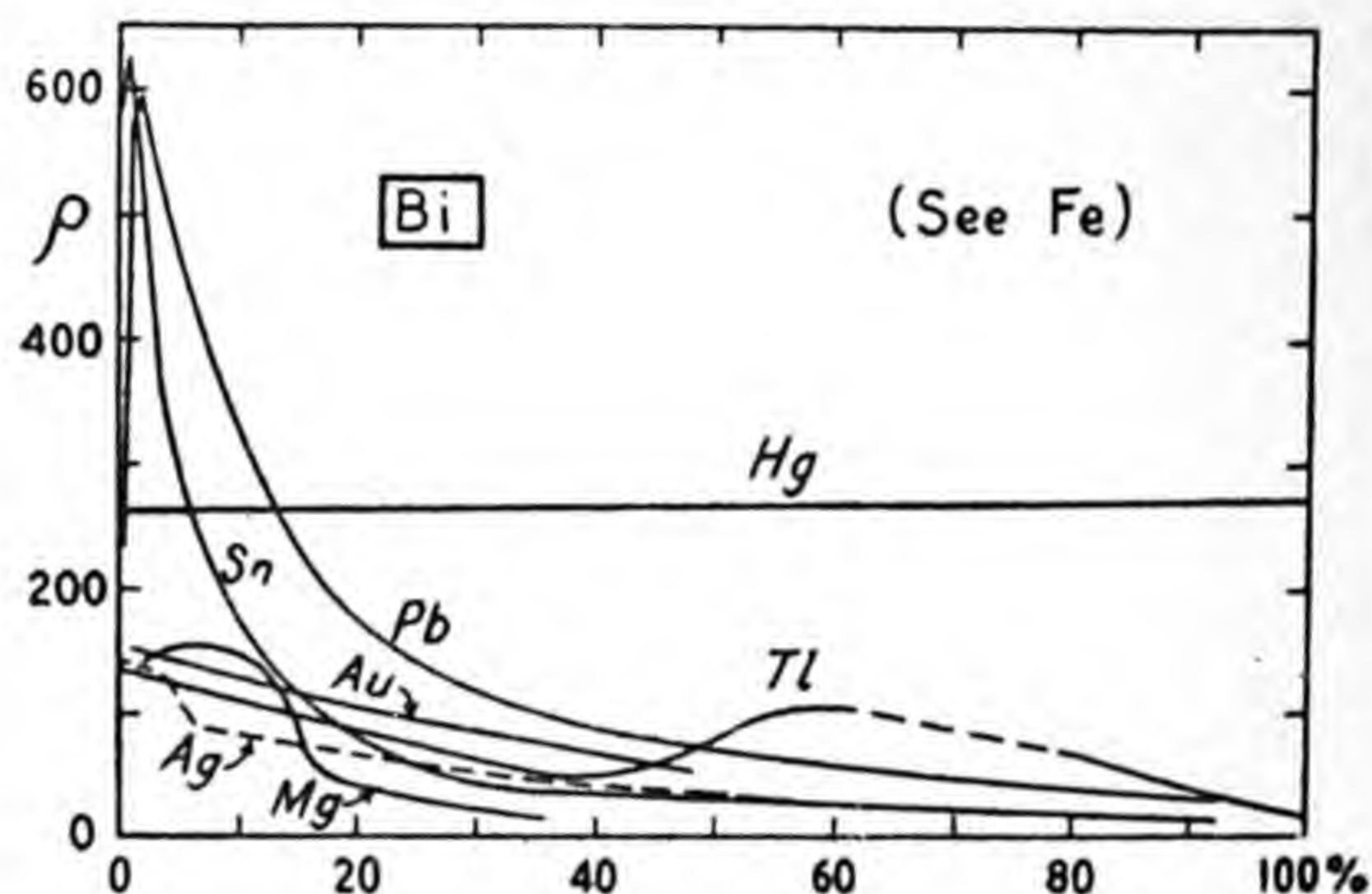
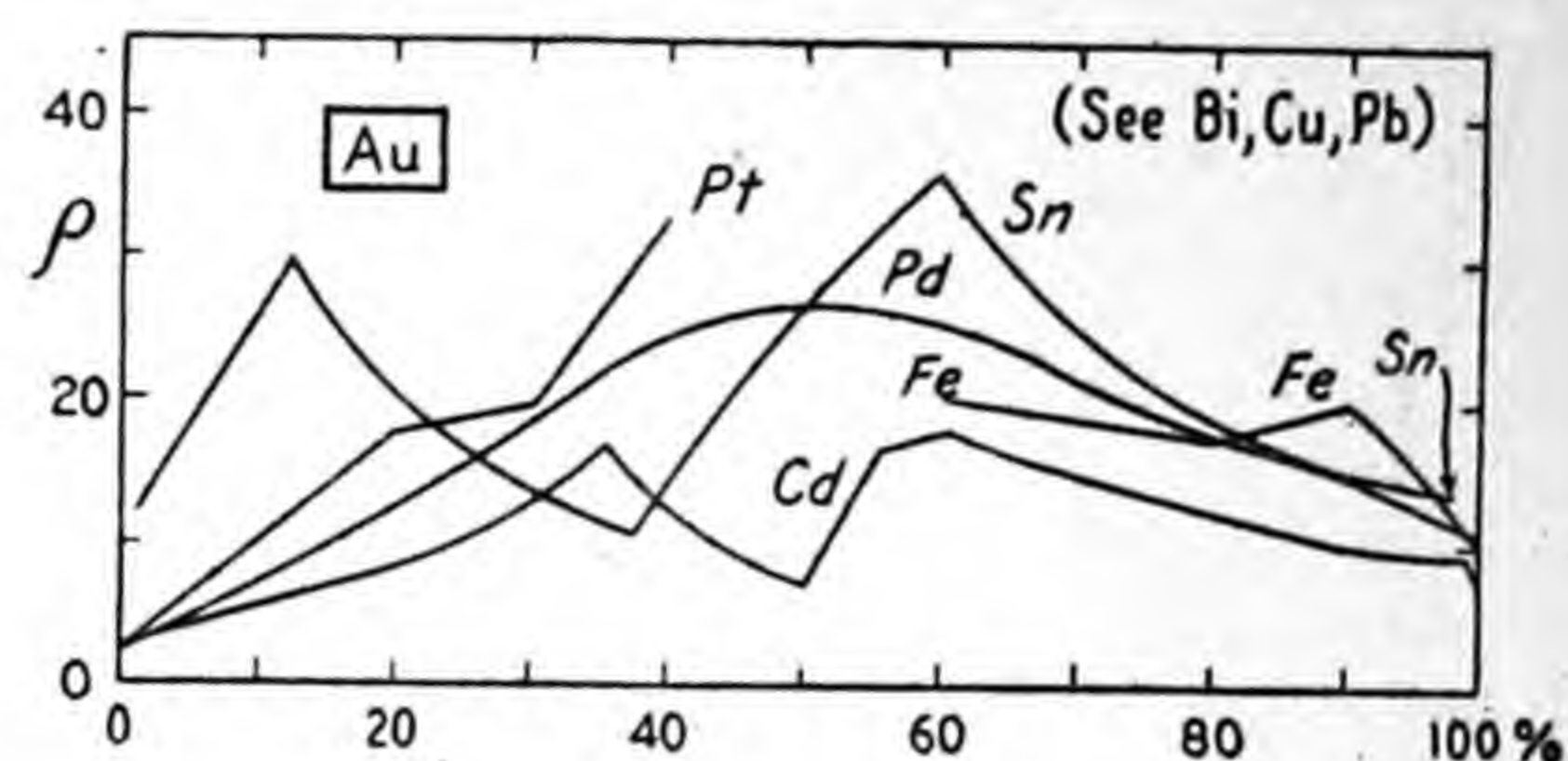
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- (50) Campbell, 83, 15: 138; 20. (51) Campbell and Whitney, 140, 110: 291; 24. (52) Capp, 115, 77: 274; 04. (53) Carpenter, Hadfield and Longmuir, 116, 80: 708, 745, 779, 822; 05. (54) Carpenter, Hadfield and Longmuir, 403, 1906: 857. (55) Caswell, 2, 12: 226; 18. (56) Cattaneo, 23, 27 II: 419; 91. (57) Chevallier, 34, 130: 120, 1612; 00. (58) Chevallier, 51, 1: 157; 02. (59) Chevenard, 34, 181: 28; 25.
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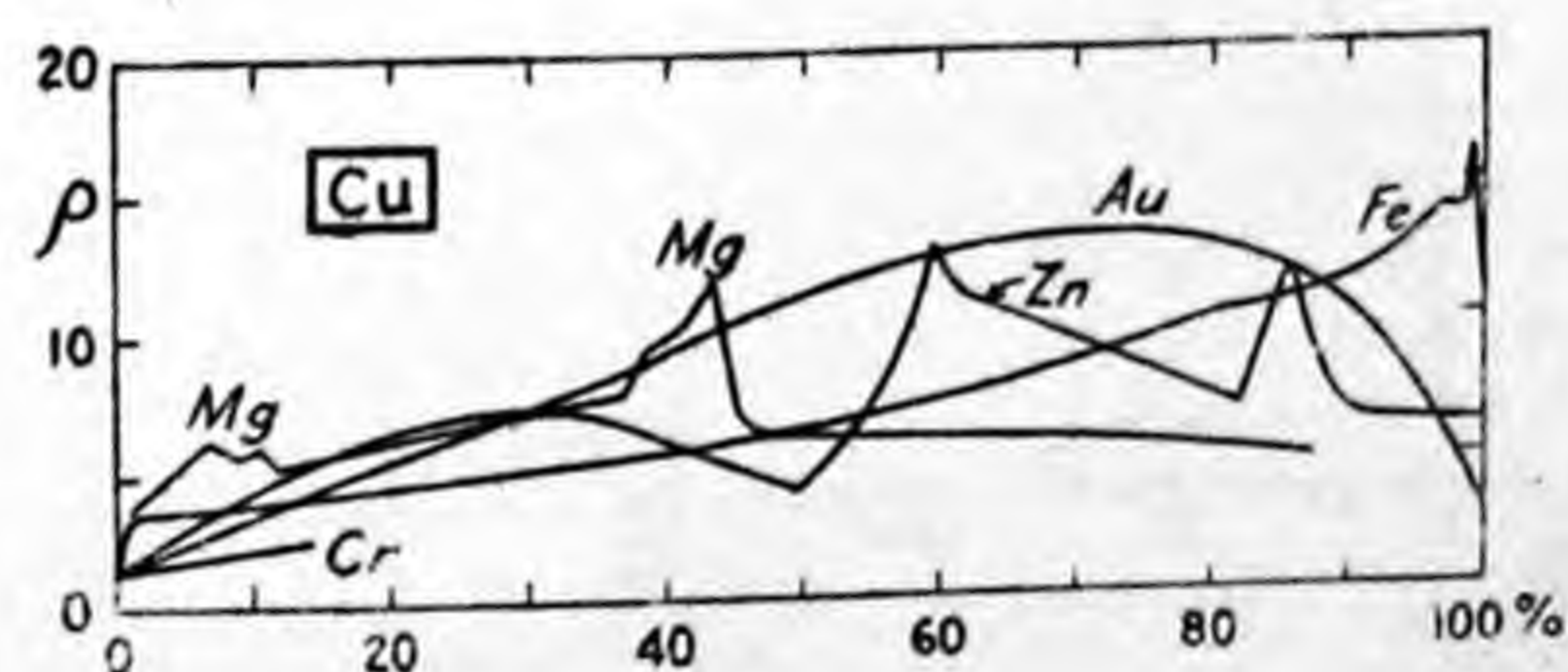
Resistivity ( $\rho$ ) of binary alloys. (For other and more accurate data, see Table 2.) The symbol of the metal common to the alloys of a chart is enclosed in a square, and the abscissae = Wt. % of the other metal. Unit of  $\rho = 10^{-6}$  ohm-cm.



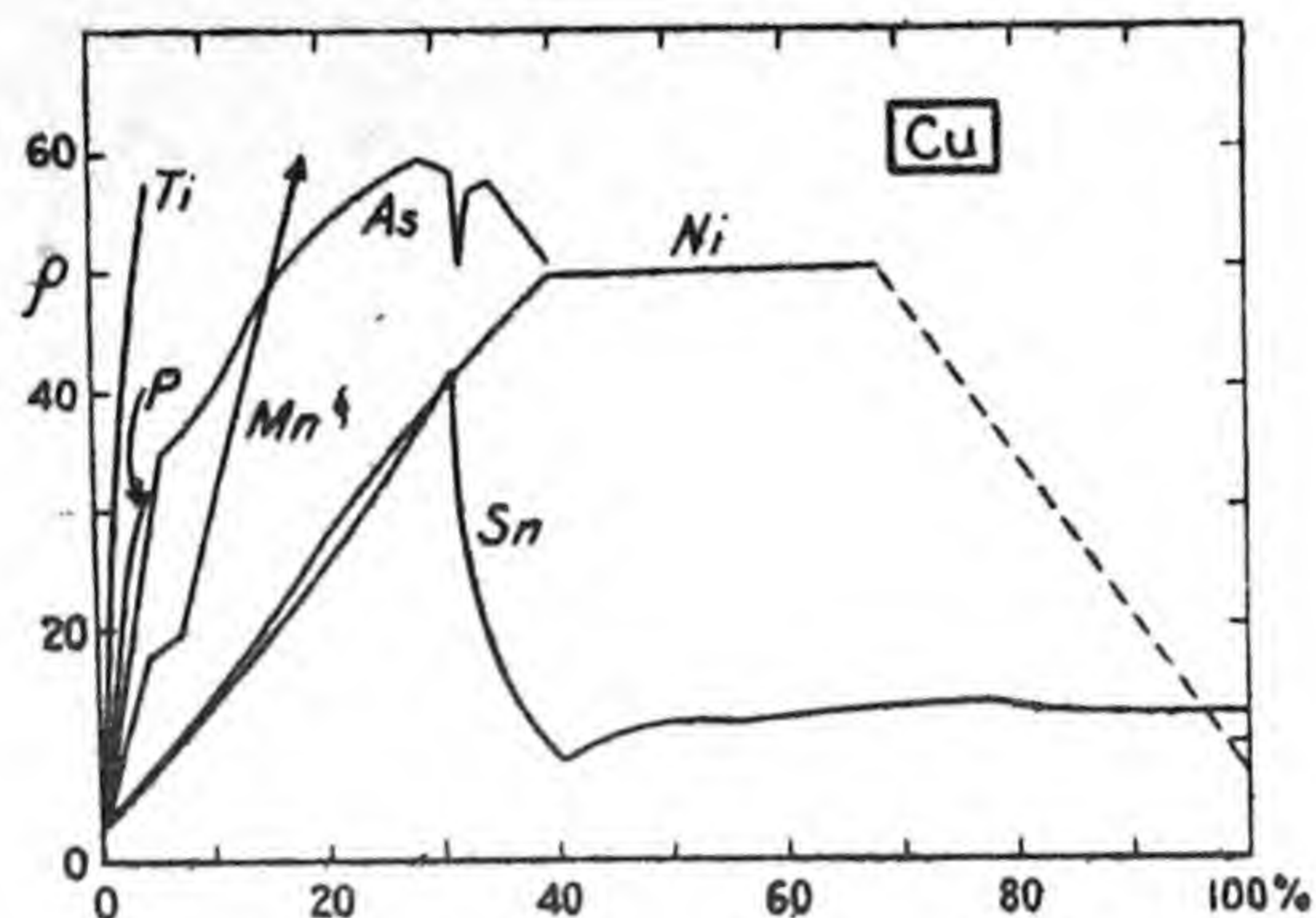
\* For Al-Mn: At 30.4% Mn,  $\rho = 500$ ; at 46.9% Mn,  $\rho = 2000$ .



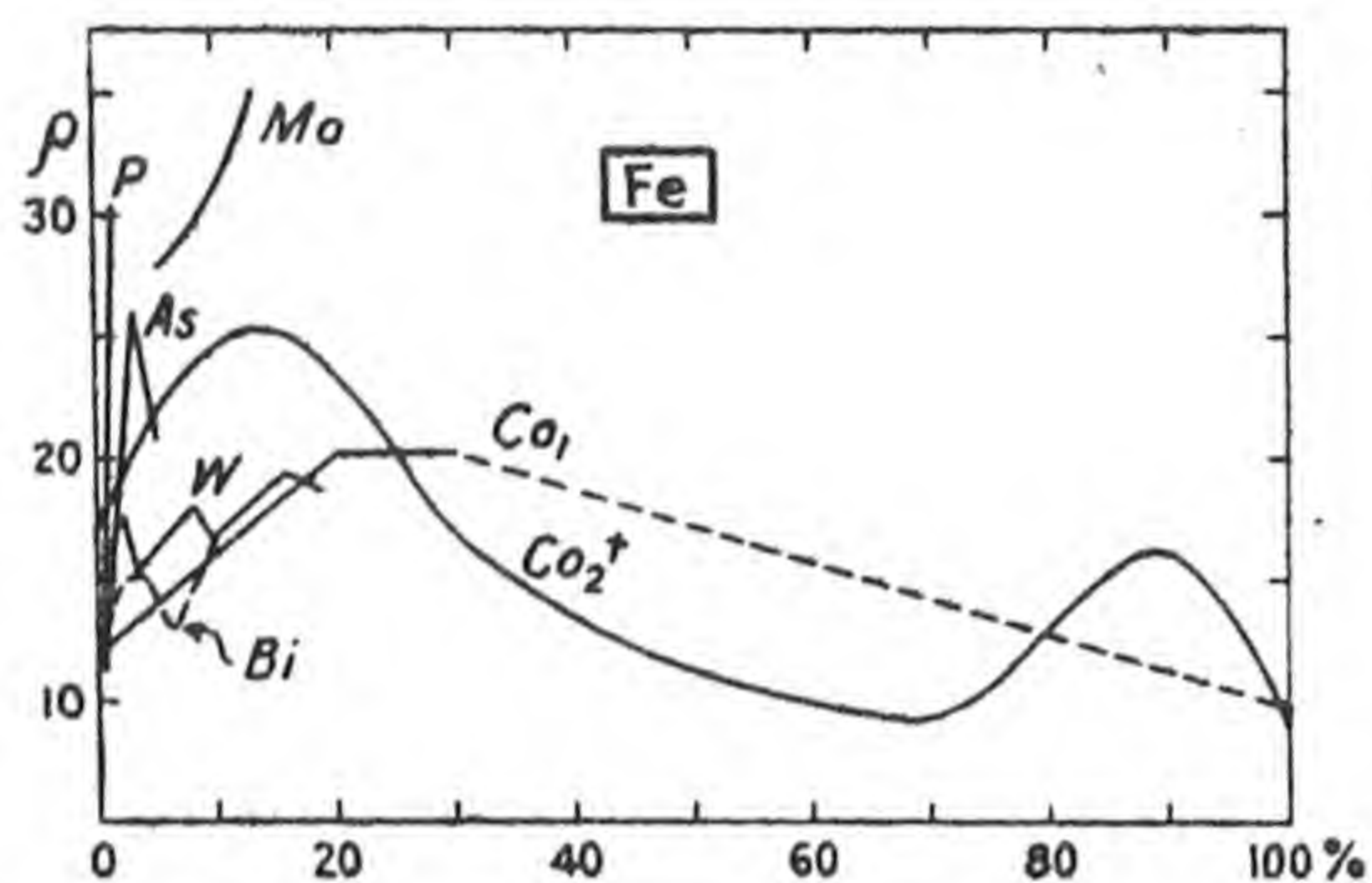
† For (Co, Fe<sub>1</sub>) and (Fe, Co<sub>1</sub>) the materials were pure, for (Co, Fe<sub>2</sub>) and (Fe, Co<sub>2</sub>) they were not; see Table 2, Fe-Co (120) and Fe-Co-x (121).



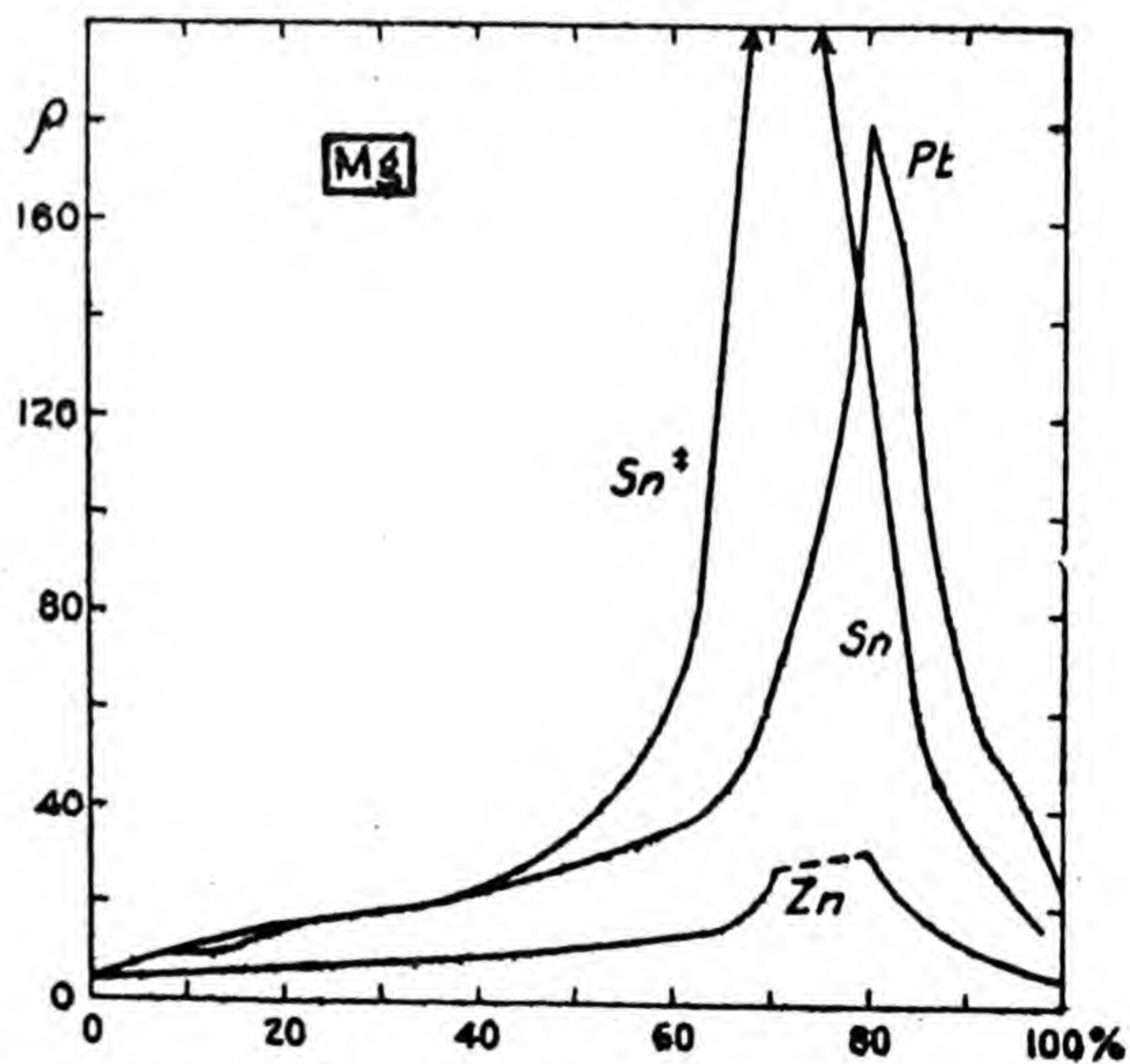
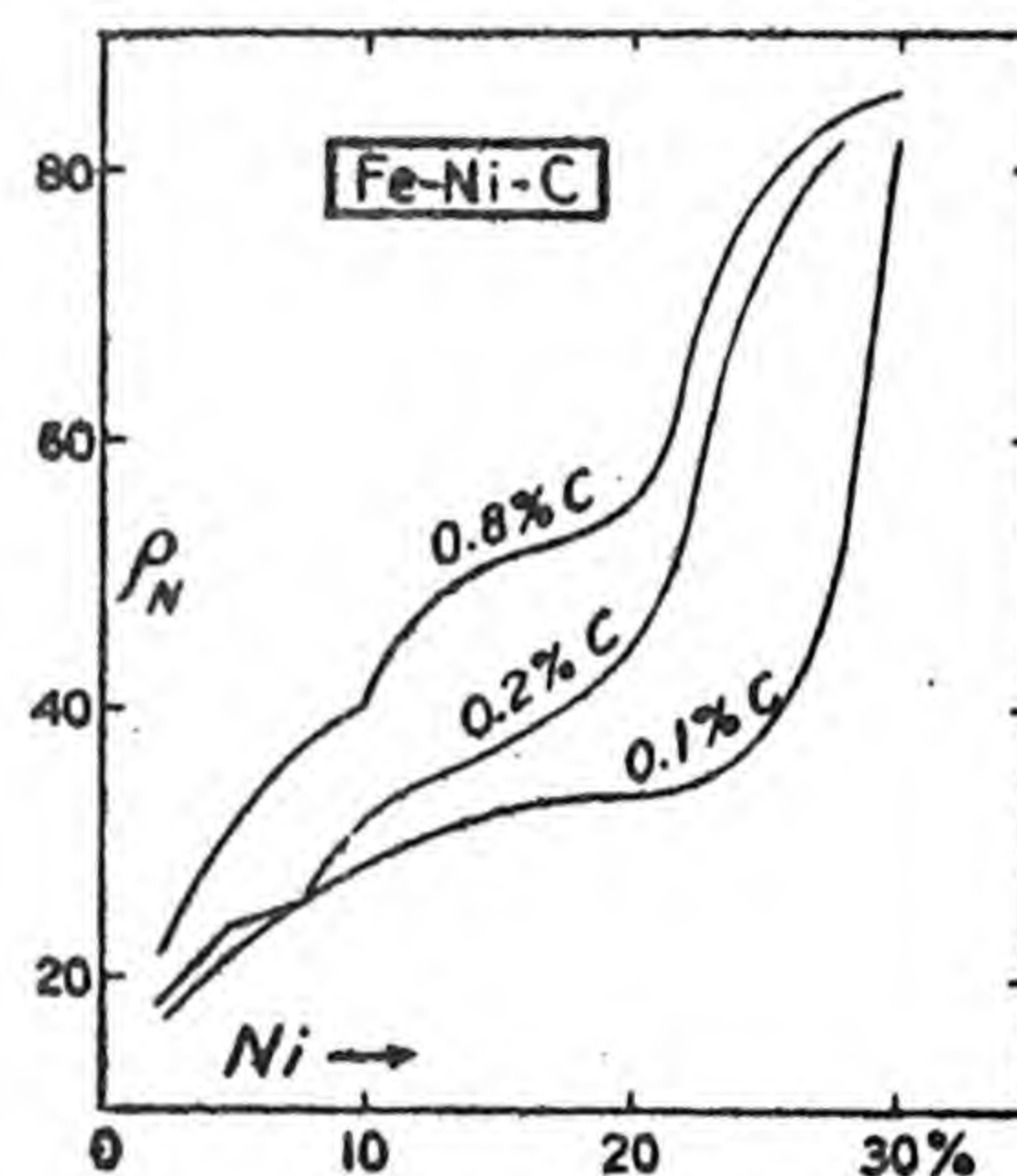
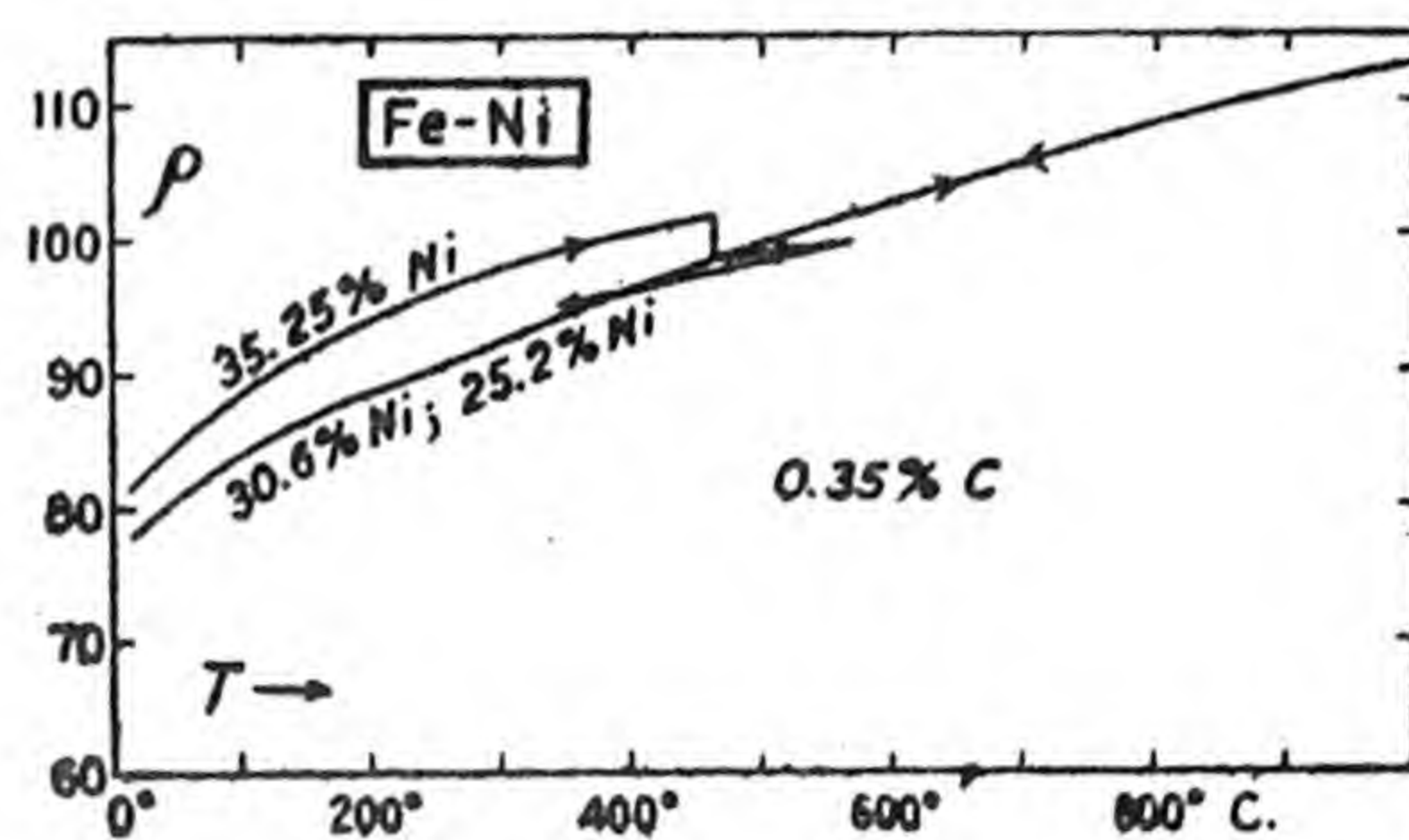
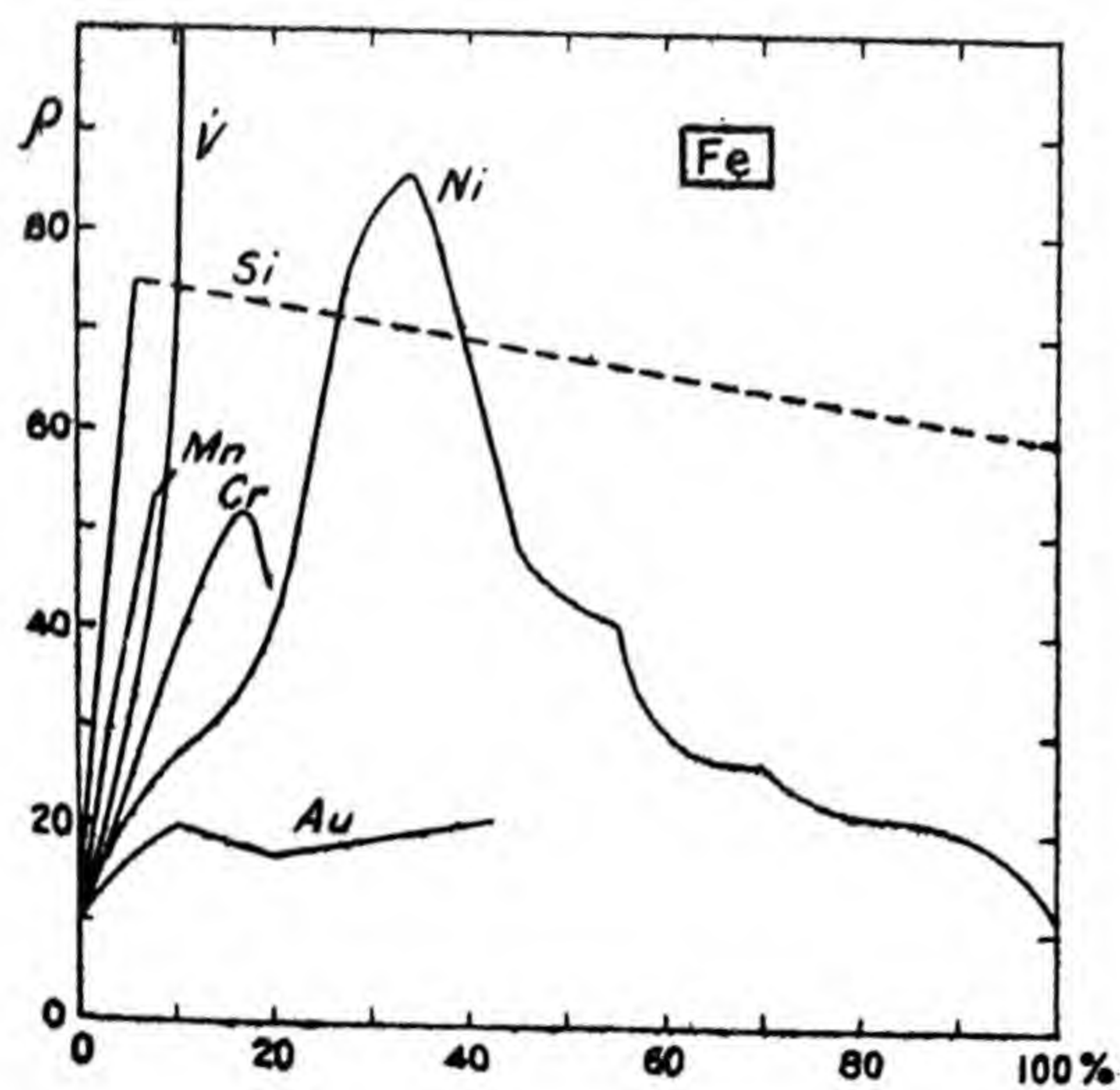




§ For Cu-Mn: At 40% Mn,  $\rho = 133$ ; at 60% Mn,  $\rho = 164$ .

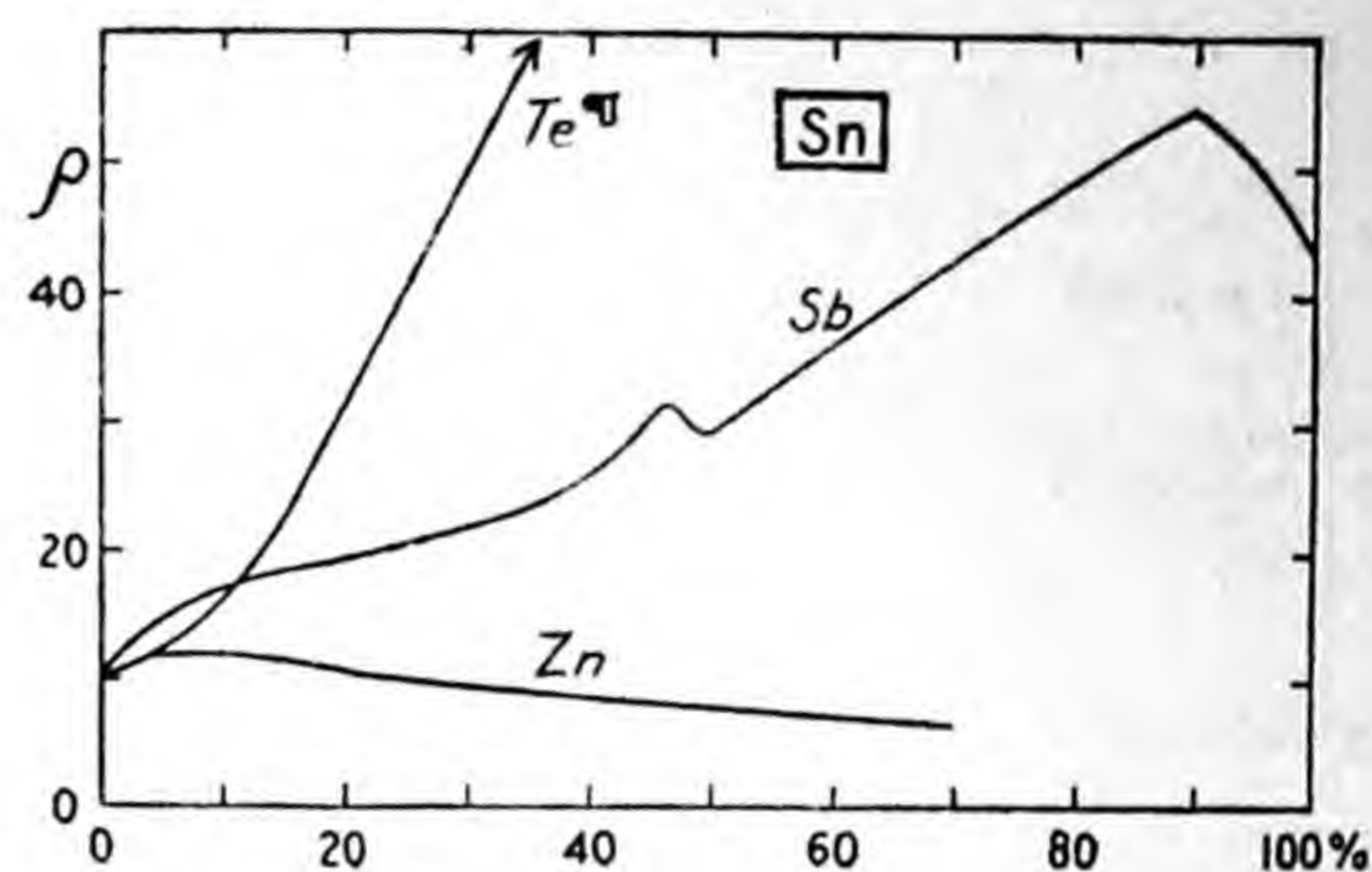
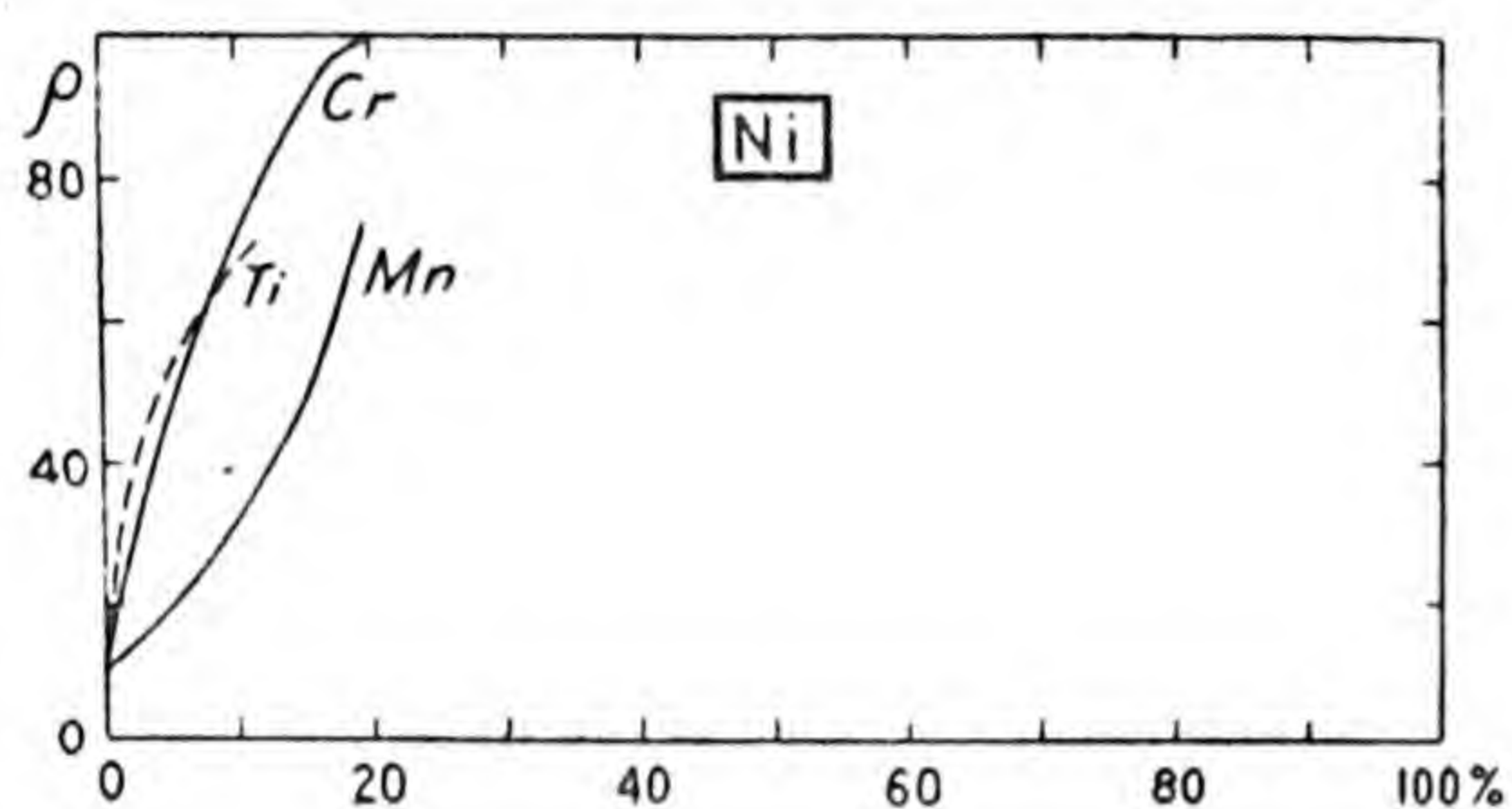


† For (Co, Fe<sub>1</sub>) and (Fe, Co<sub>1</sub>) the materials were pure, for (Co, Fe<sub>2</sub>) and (Fe, Co<sub>2</sub>) they were not; see Table 2, Fe-Co (120) and Fe-Co-x (121).

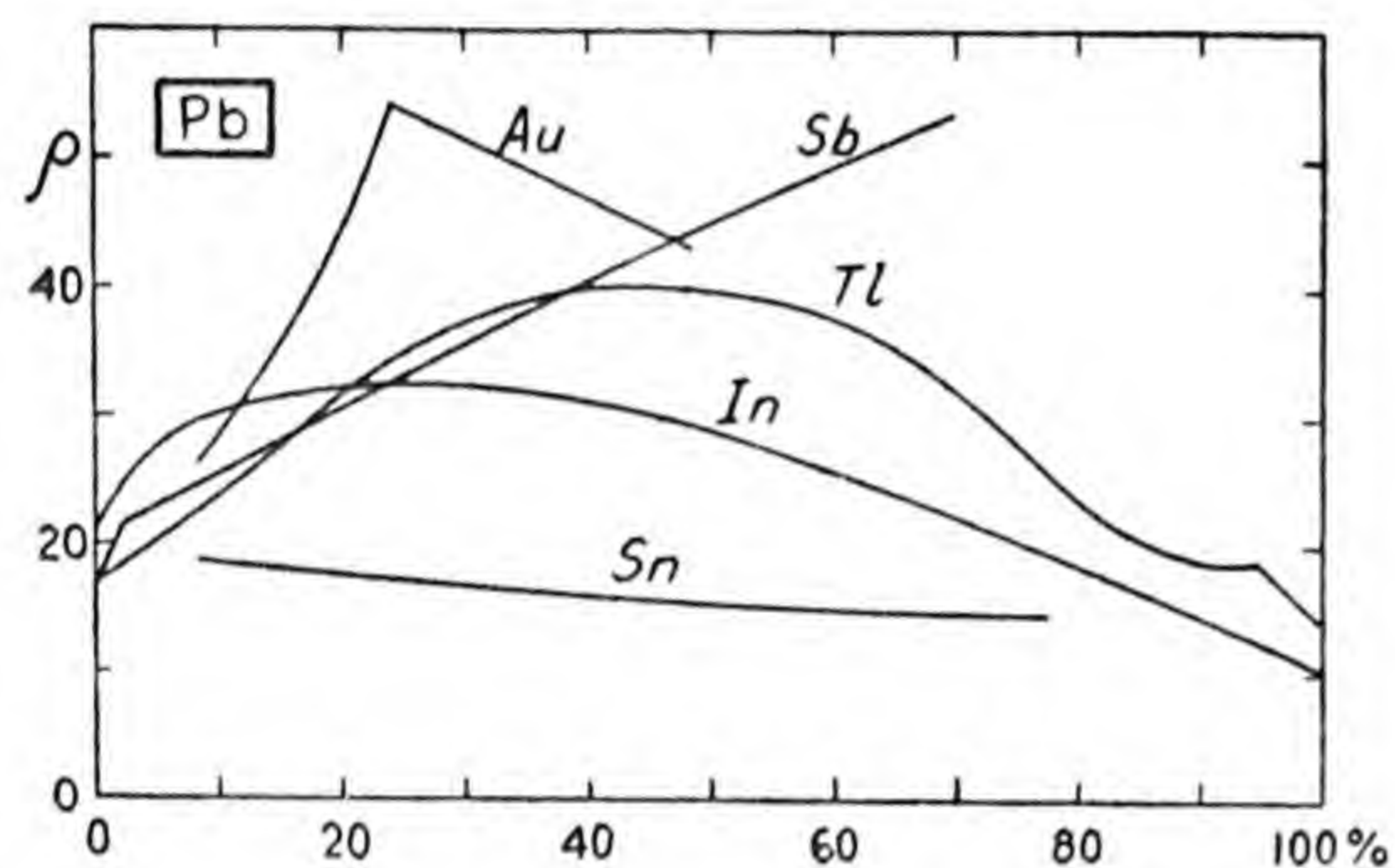


† For Mg-Sn: At 71% Sn,  $\rho_{21} = 1100$ .

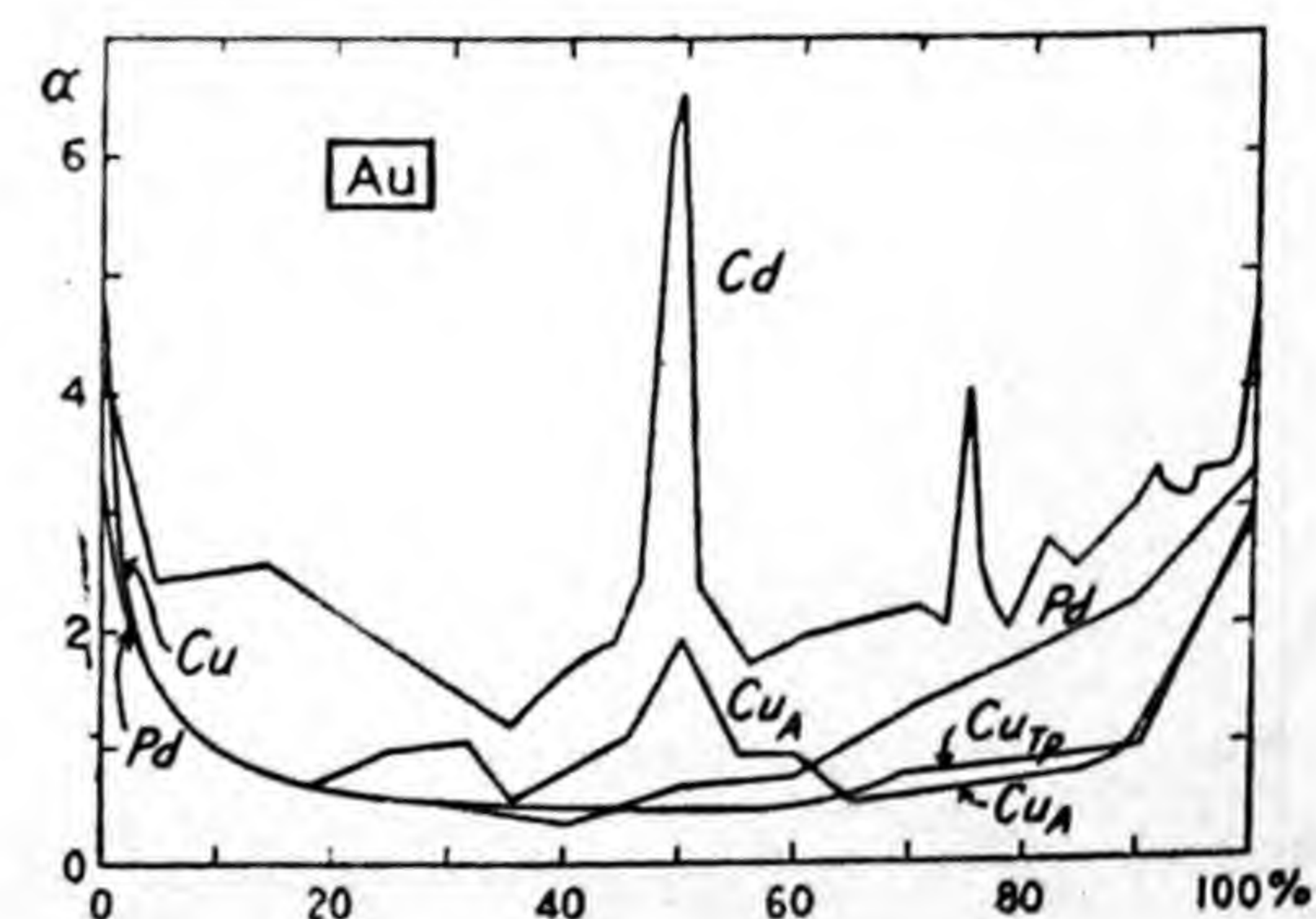
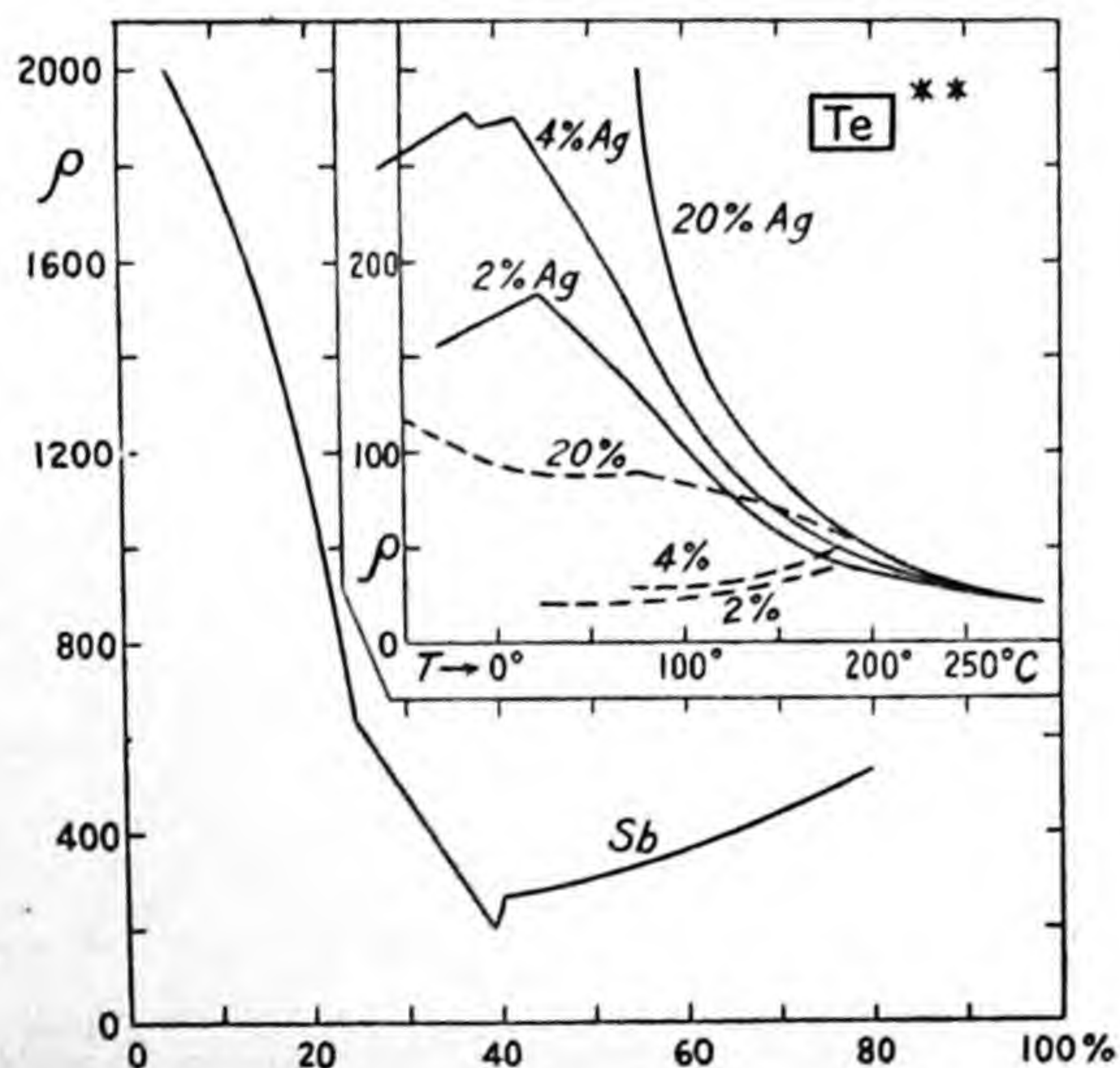
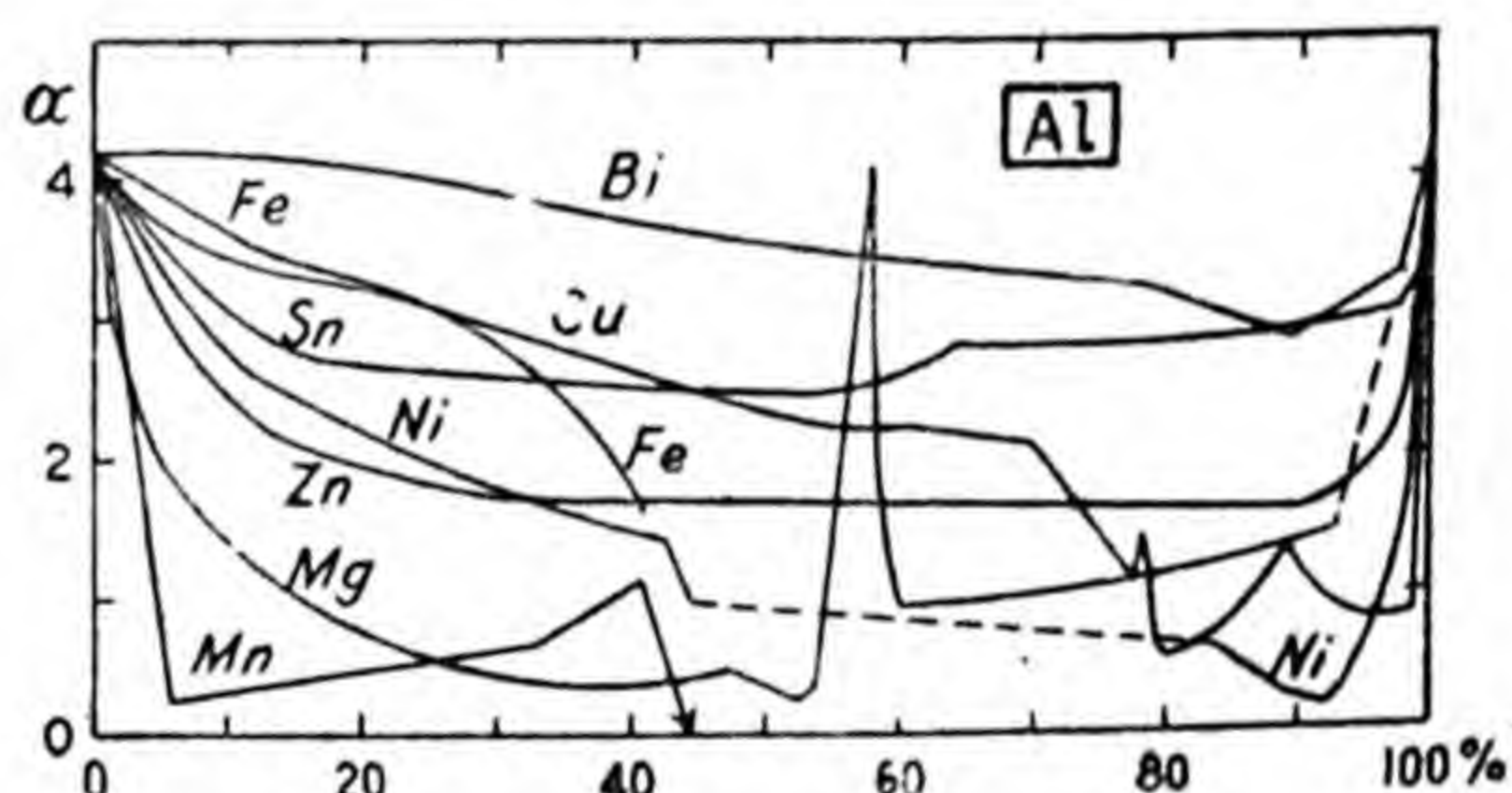
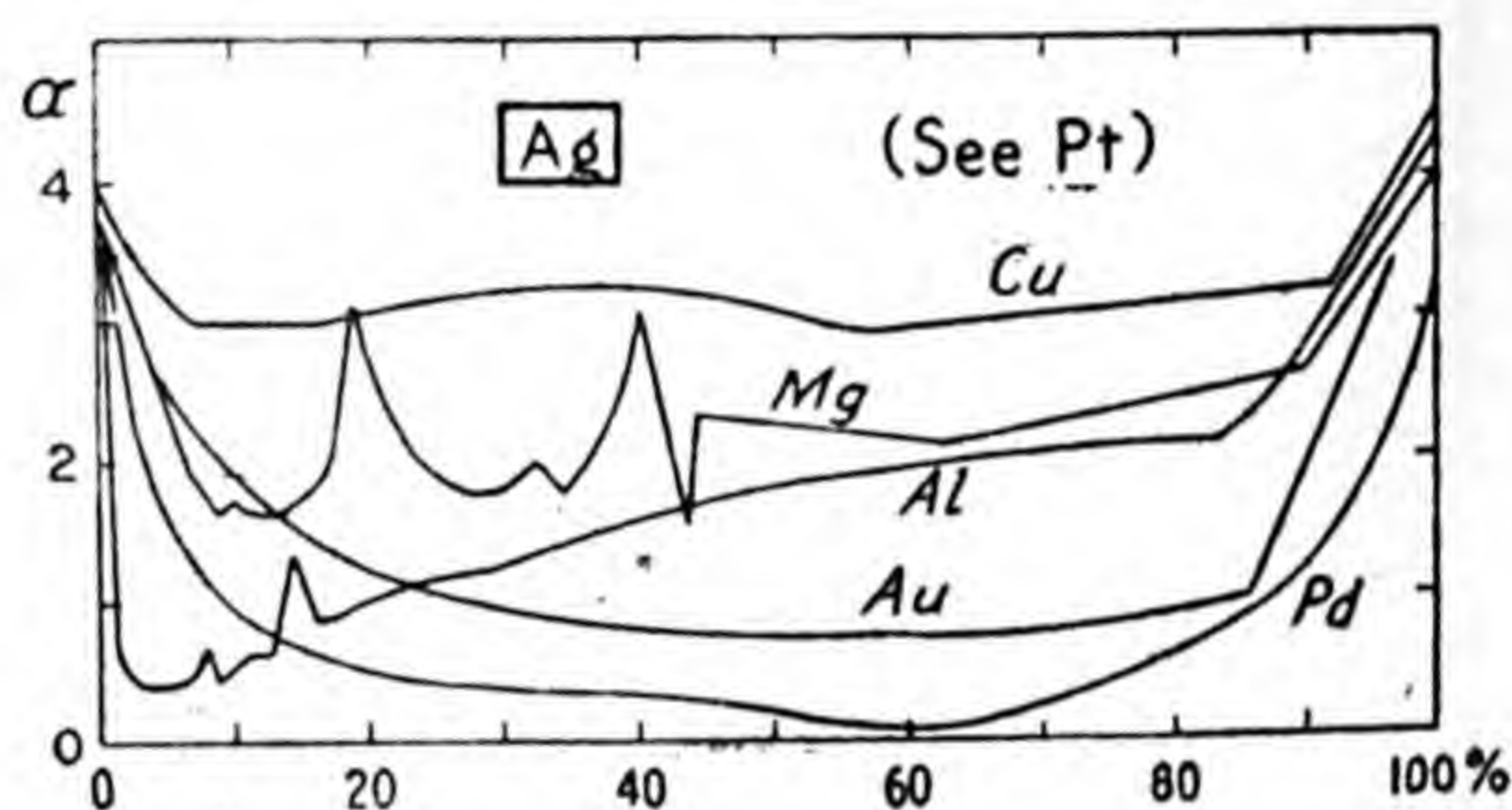
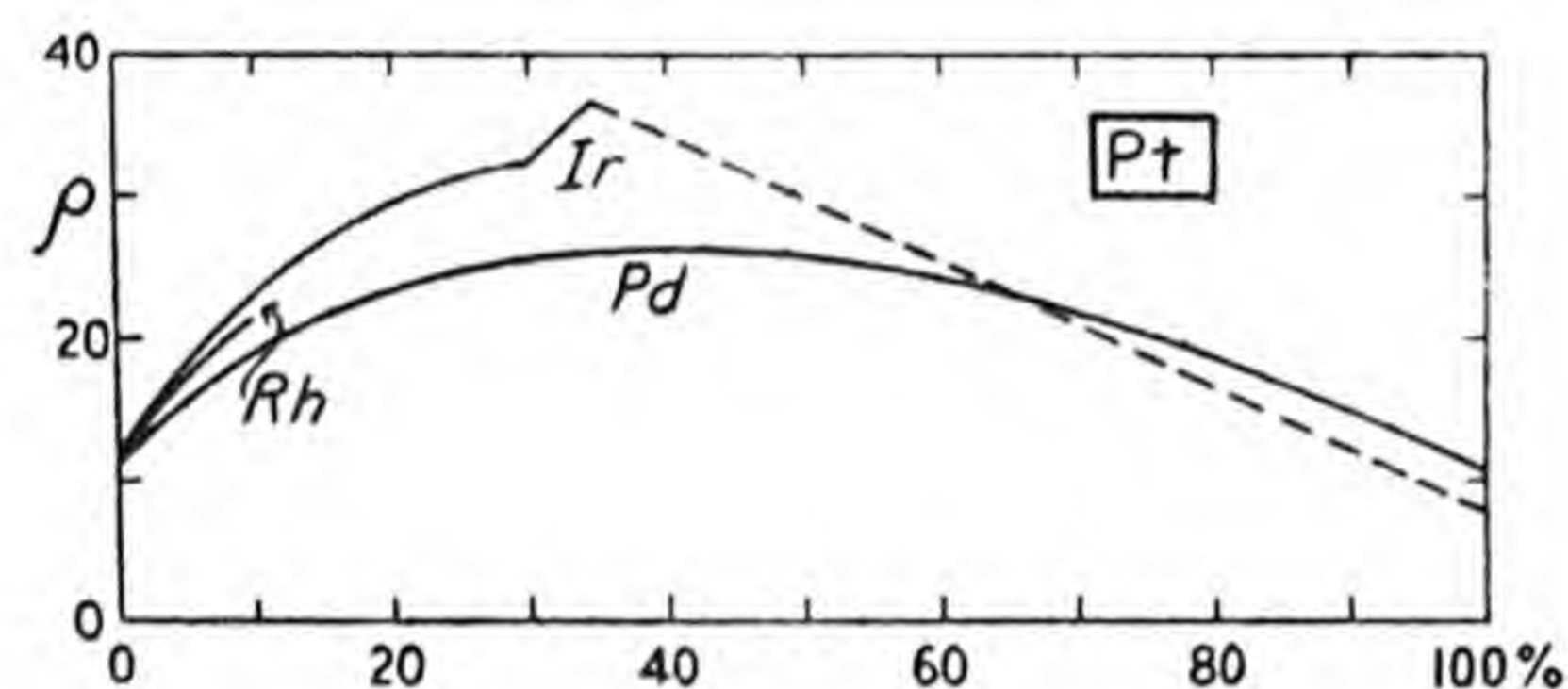




\* For Sn-Te: At 90% Te,  $\rho = 2780$

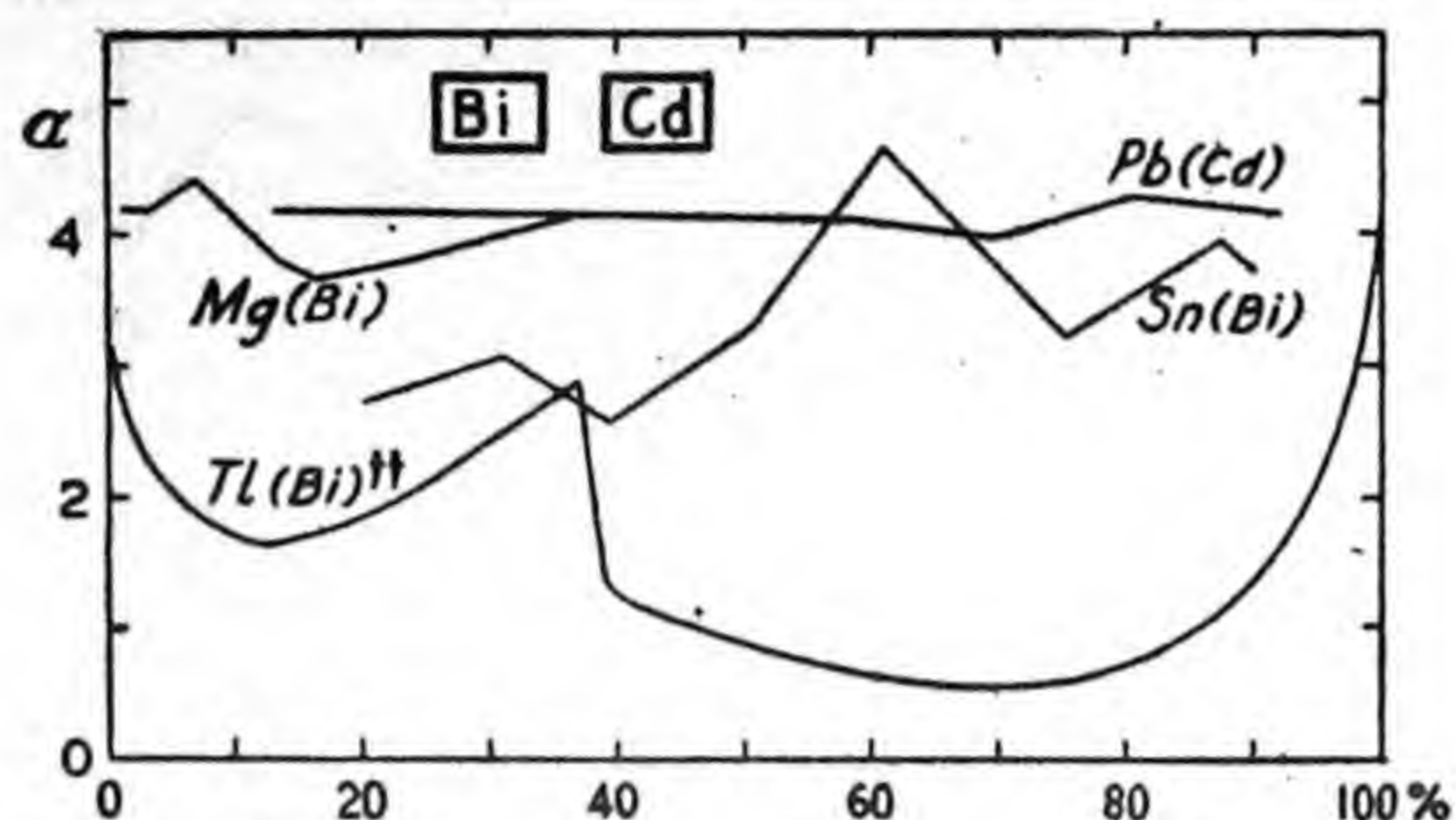


Temperature coefficient ( $\alpha$ ) of resistivity of binary alloys. (For other and more accurate data, see Table 2.) The symbol of metal common to the alloys of a chart is enclosed in a square, and the abscissa = Wt. % of the other metal. Unit of  $\alpha = 0.1\%$  per  $1^\circ\text{C}$ .

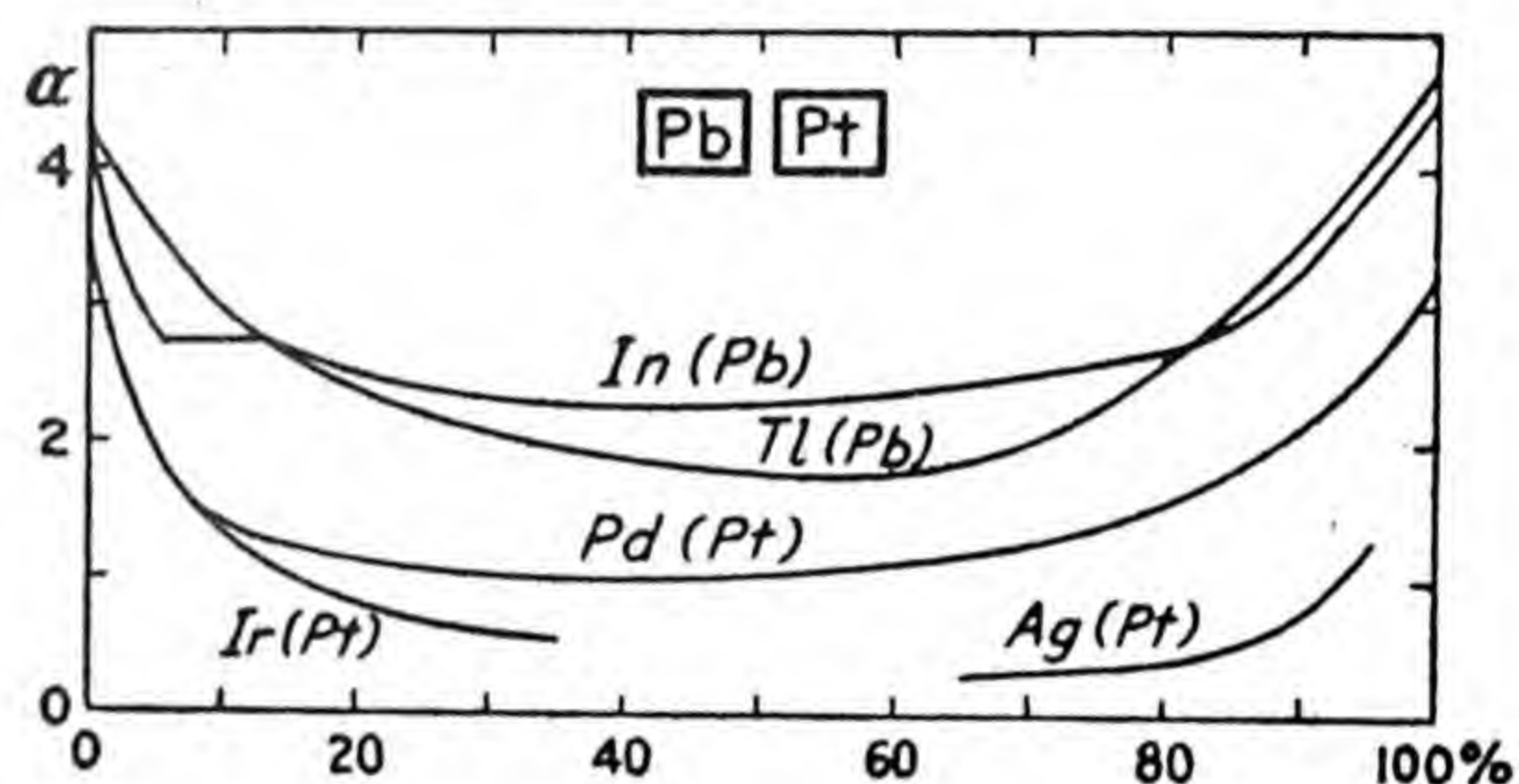
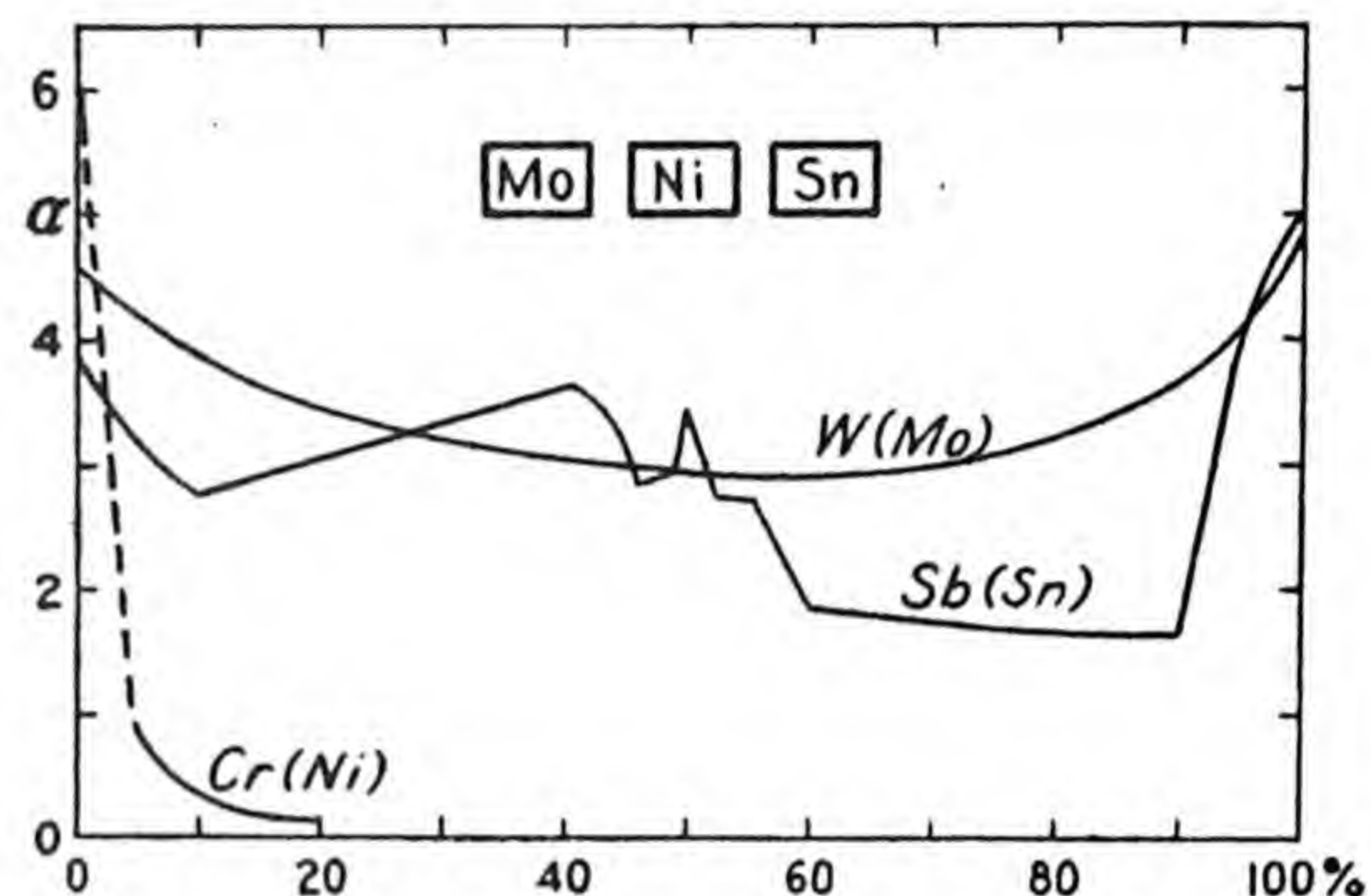
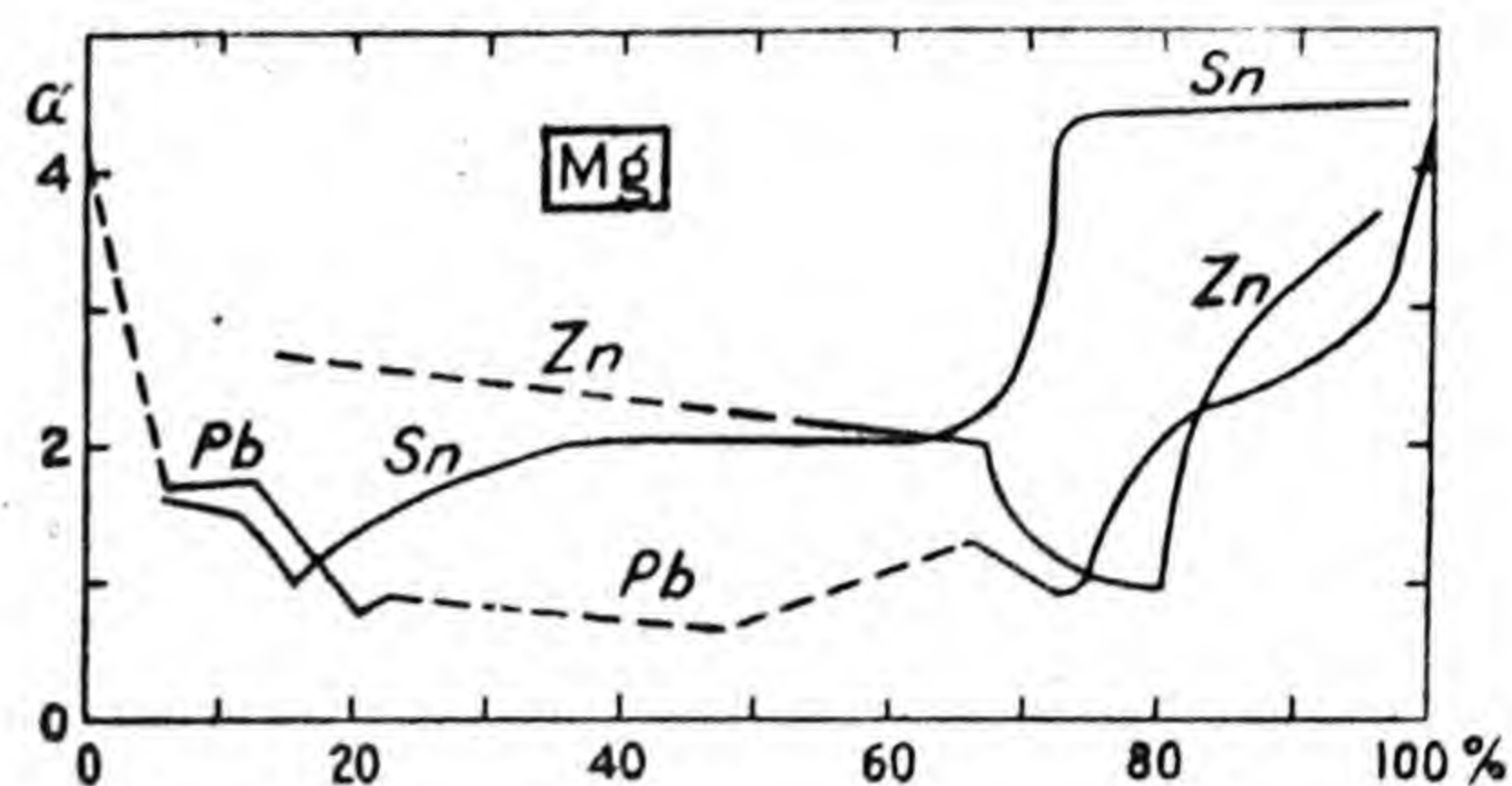
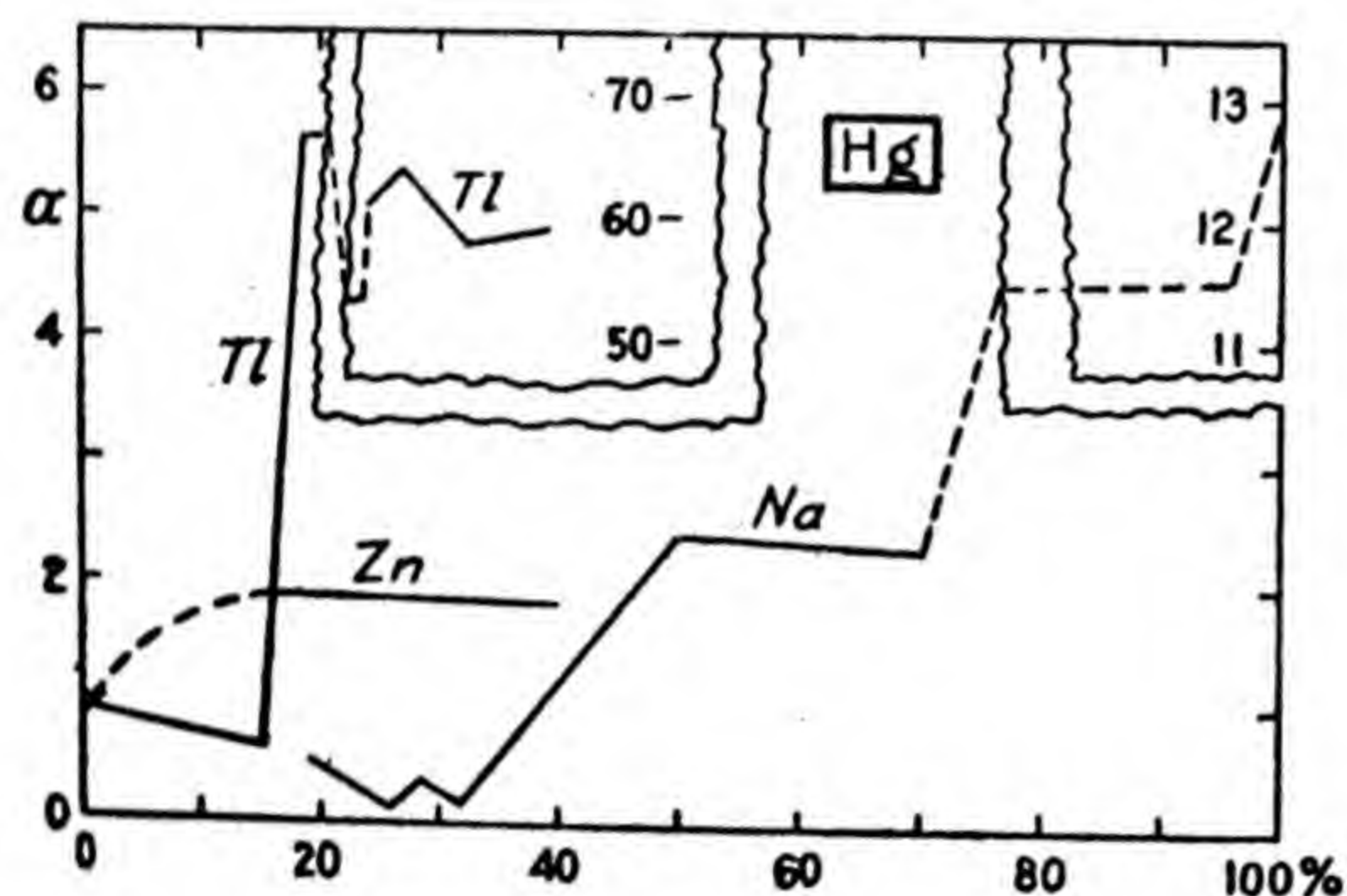
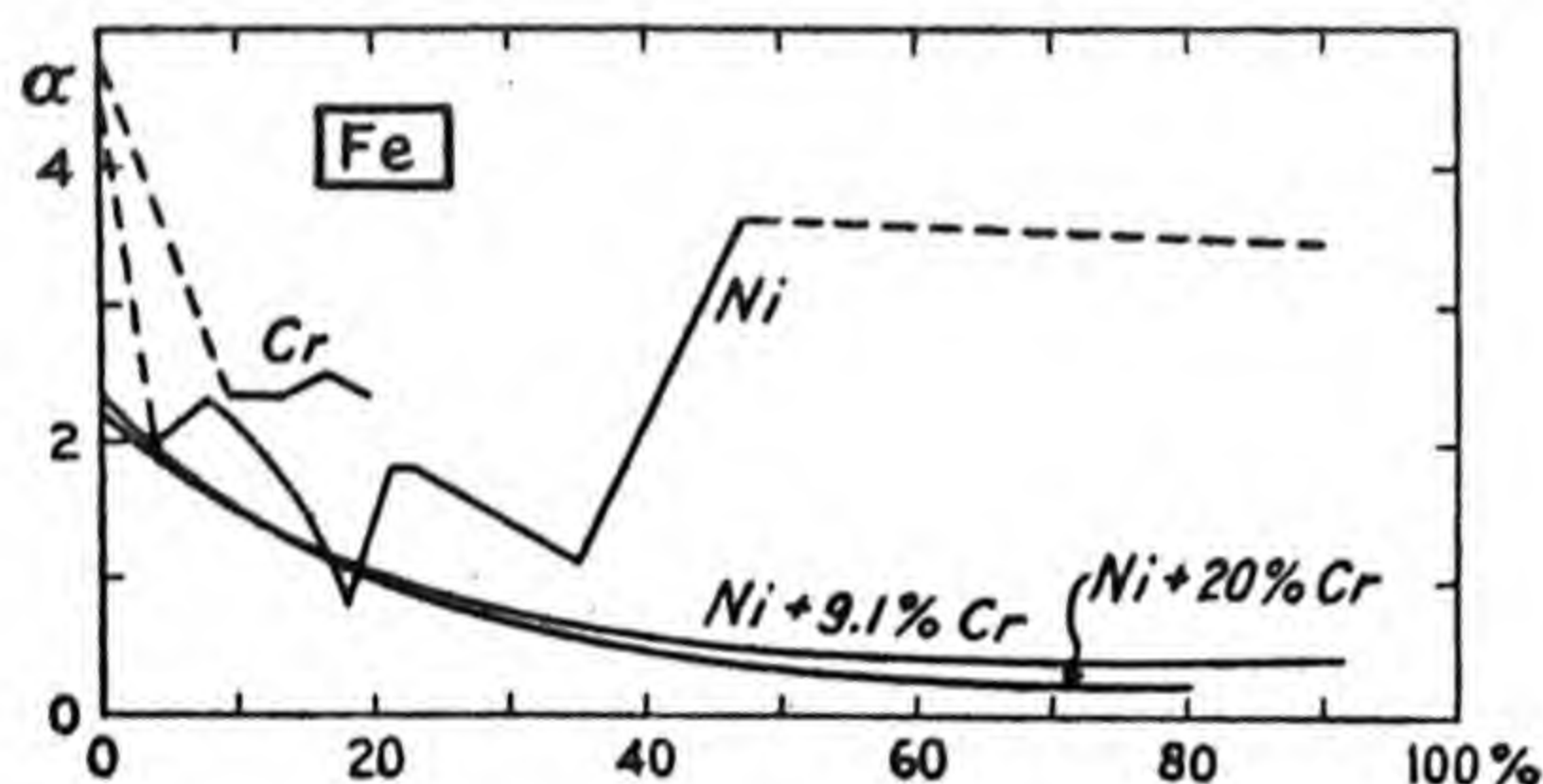
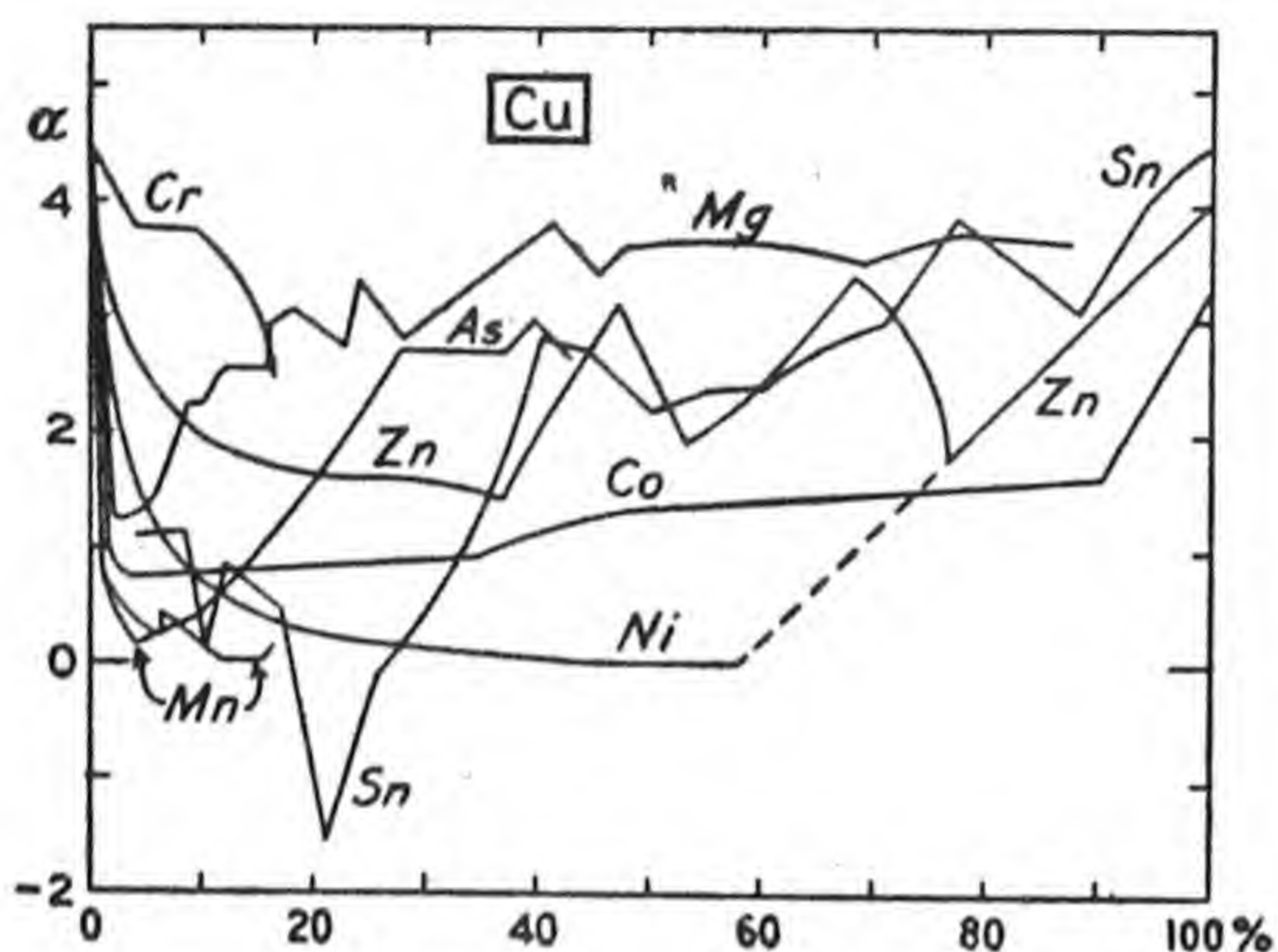


\*\* For Te-Ag, continuous lines correspond to  $\rho_A$ , broken to  $\rho_f$  (cooled rapidly from melting point).





†† Curve for Tl(Bi) is for  $\alpha_0$  at 0°C, cf. Table 2, Bi-Tl.



- (70) Ebeling, 243, 16: 87; 96. (71) Englisch, 8, 45: 592; 92. (72) Eucken and Gehlhoff, 88, 14: 169; 12. (73) Feussner and Lindeck, 243, 9: 233; 89. (74) Feussner and Lindeck, 89, 2: 501; 95. (75) Fischbeck, 93, 125: 1; 22. (76) Fleming, 325, 15: 239; 99. (77) Fleming, 5, 66: 50; 00. (78) Fournel, 34, 143: 46, 287; 06. (79) Friedrich, 192, 5: 529; 08. (80) Geibel, 93, 69: 38; 10. (81) Geibel, 93, 70: 240; 11. (82) Geiss and van Liempt, 93, 128: 355; 23. (83) Geross, 22, 2 II: 344; 86. (84) Goerens, 417, 3: 320; 11. (85) Goerens, 74, 10: 608; 13. (86) Gray, 552, No. 4; 12. (87) Greaves, 47, 7: 218; 12. (88) Grenet, 74, 1: 353; 04. (89) Gressman, 2, 9: 20; 99. (90) Griffiths, 62, 184: 361; 94. (91) Griffiths, 115, 123: 475; 27. (92) Grimaldi, 170, 4: 46; 87. (93) Grüneisen, 8, 3: 43; 00. (94) Guertler, 93, 51: 397; 06. (95) Guertler, 9, 13: 441; 07. (96) Guertler, 200, 5: 17; 08. (97) Guertler, 63, 9: 404; 08. (98) Guertler, 63, 11: 476; 10. (99) Guertler, 47, 6: 135; 11. (100) Guertler, 9, 18: 601; 12. (101) Guertler, 95, 11: 41; 19. (102) Guertler and Schulze, 7, 104: 90; 23. (103) Guertler and Schulze, 7, 104: 269; 23. (104) Guertler and Schulze, 7, 106: 1; 23. (105) Guillaume, 34, 125: 235; 97. (106) Guillaume, 51, 7: 262; 98. (107) Guillaume, 149, 5: 255, 305; 98. (108) Guillet, 140, 90: 66; 14. (109) Guillet, 74, 20: 656; 23. (110) Guillet, 34, 177: 953; 23. 126, 3: 641; 23. (111) Guillet and Ballay, 34, 172: 1576; 21. (112) Guillet and Ballay, 34, 176: 1800; 23. (113) Guillet and Ballay, Proc. verbal l'assoc. Fr. Belge pour l'essai des mat., 16: 6; 23. (114) Gumlich, 101, 40: 334; 10. (115) Gumlich and Goerens, 83, 8: 98; 12. (116) Gumlich and Goerens, 77, 39: 765; 19. (117) Haas, 101, 16: 272; 95. 8, 52: 673; 94. (118) Hadfield, 140, 1892 II: 49. (119) Haken, 8, 32: 291; 10. (120) Hart, 80, 64: 554; 21. (121) Herold, 93, 112: 131; 20. (122) Hine, 1, 39: 882; 17. (123) Honda, 159, 7: 59; 18. (124) Honda, 159, 8: 51; 19. (125) Honda and Matsushita, 159, 8: 89; 19. (126) Honda and Ogura, 159, 3: 113; 14. (127) Honda and Simidu, 159, 6: 219; 17. (128) Hopkinson, 62, 176: 455; 86. (129) Hopkinson, 5, 47: 138; 90.



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- (190) Matthiessen and Vogt, 62, 154: 167; 64. (191) Maurer, 74, 5: 711; 08. (192) Mehl, 78, 46: 149; 24. (193) Merica, 33, 24: 375, 558, 649; 21. (194) Merica, 422, 57: 484; 22. (195) Merica, Waltenberg and Scott, 80, 64: 41; 21. (196) Mithaler, 8, 46: 297; 92. (197) Müller, 192, 7: 730; 10. (198) Munker, 192, 9: 185; 12. (199) National Malleable and Steel Castings Co., Cleveland, Ohio, O.
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- (240) Salda, 53, 46: 994; 14. (241) Salda, 417, 7: 195; 16. (242) Schenck, 63, 8: 239; 07. (243) Schenck, 9, 15: 648; 09. (244) Schenck, 8, 32: 261; 10. (245) Schimank, 8, 45: 706; 14. (246) Schleicher and Guertler, 9, 20: 237; 14. (247) Schulze, 8, 9: 555; 02. (248) Scott and Movius, 31A, 16: 537; 20. (249) Sebast, 552, No. 8; 16.
- (250) Sebast and Gray, 78, 29: 569; 16. (251) Sedström, 8, 59: 134; 19. (252) Simidu, 159, 6: 111; 17. (253) Skaupy, 7, 58: 560; 07. (254) Smirnov and Kurnakov, 93, 72: 31; 11. 169, 14: 623; 10. (255) Smith, 3, 16: 450; 08. (256) Smith, 2, 28: 107, 429; 09. (257) Smith, 33, 25: 1178; 21. (258) Smith, 143, 192: 69, 157; 21. (259) Somerville, 2, 30: 268, 532; 10.
- (260) Somerville, 2, 31: 275; 10. (261) Somerville, 2, 33: 77; 11. (262) Stäblein, 96, 20: 209; 23. (263) Steinmetz, 78, 11: 81; 07. (264) Stepanov, 93, 60: 209; 08. (265) Stepanov, 93, 78: 1; 12. 53, 44: 910; 12. (266) Sturm, *Diss.*, Rostock, 1904. 427, 29: 143; 05. (267) Swinden, 140, 80: 223; 09. (268) Swinden, 417, 3: 66; 11. (269) Swinden, 417, 5: 100; 13.
- (270) Swoboda, 107, 77: 944; 21. (271) von Szily, 51, 8: 329; 99. (272) von Szily, 34, 128: 927; 99. (273) Taylor, 133, 1851: 431. (274) Tomlinson, 5, 56: 103; 94. (275) Thomson, 47, 14: 3; 15. (276) Thompson, 46, 54: 222; 16. (277) Thompson and Miller, 1, 28: 1115; 06. (278) Thompson and Whitehead, 5, 102: 587; 23. (279) Urazov, 169, 14: 675; 10. 93, 73: 31; 12.
- (280) Vanstone, 4, 105: 2617; 14. (281) Voigt, 93, 120: 309; 21. (282) Weber, 8, 23: 447; 84. (283) Weber, 8, 27: 145; 86. (284) Weber, 8, 31: 243; 87. (285) Weber, 8, 34: 576; 88. (286) Weber, 8, 68: 705; 99. (287) Wedding, 101, 9: 172; 88. (288) Wedding, *Various papers in Verh. Vereins zur Beförderung des Gewerbfleißes*, 1892-1902. (289) Wiechart, 8, 52: 67; 94.
- (290) Weiller, 101, 3: 83, 157; 82. (291) Williams, 3, 13: 635; 07. (292) Williams, 3, 50: 589; 25. (293) Willows, 3, 48: 433; 99. (294) Willows, 3, 12: 604; 06. 63, 8: 173; 07. (295) Wilson, 46, 31: 321; 02. (296) Wilson, 133, 1903: 777. 121, 51: 898; 03. (297) Wilson, 121, 67: 907; 11. (298) Yensen, 86, No. 77; 15. (299) Yensen, 86, No. 83; 15.
- (300) Yensen, 119, 34: 2455; 15. (301) Yensen, 129, 39: 791; 20. (302) Yensen, 107, 75: 774; 20. (303) Yensen, 45, 16: 366; 24. (304, 305) Yensen, 129, 43: 145; 24. (306) Yensen and Gatward, 86, No. 95; 17. (307) Tanabe, 47, 32: 415; 24.



ELECTROELASTIC AND PYROELECTRIC PHENOMENA<sup>1</sup>

W. G. CADY

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Electrostriction.	Électrostriction.	Elektrostriktion.	Elettrostrizione.....	207
Piezoelectricity.	Piézoélectricité.	Piezoelektrizität.	Piezolettricità.....	208
Pyroelectricity.	Pyroélectricité.	Pyroelektrizität.	Pirolettricità.....	209
Piezo and pyro effects at room temperature:	Piézo-effets et pyro-effets à la température de la chambre.	Piezo- und Pyro-Effekt bei Zimmertemperatur.	Effetti piezo e piro a temperatura ordinaria....	209
Tourmaline.	Tourmaline.	Turmalin.	Tormalina.....	210
Quartz.	Quartz.	Quarz.	Quarzo.....	211
Rochelle salt (KNaC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> ·4H <sub>2</sub> O).	Sel de Rochelle (KNaC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> ·4H <sub>2</sub> O).	Seignettesalz (KNaC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> ·4H <sub>2</sub> O).	Sale di Rochelle (KNaC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> ·4H <sub>2</sub> O).....	211
Tartaric acid and cane sugar.	Acide tartrique et sucre de canne.	Weinsäure und Rohrzucker.	Acido tartarico e zucchero di canna.....	212
Pyroelectric effect: variation with temperature.	Effet pyroélectrique: variation avec la température.	Pyroelektrischer Effekt: Änderung mit der Temperatur.	Effetto piroelettrico: variazione con la temperatura.....	212

**Electrostriction.**—In general, when an isotropic dielectric is subjected to an electrostatic field  $E$ , its volume and form are changed. This phenomenon is known as *electrostriction*. The same kinds of effect occur in anisotropic dielectrics, but in them these effects are in many cases obscured by the far larger electrocrystalline ones described as piezoelectric (*see* p. 208). In electrostrictive effects, the tensions tending to stretch any element of the dielectric are proportional to  $E^2$  and to  $d\epsilon/dx$ , where  $\epsilon$  = dielectric constant and  $x$  is the amount of stretching in the direction considered. In general,  $d\epsilon/dx$  depends upon the inclination of  $x$  to  $E$ ; it may be either positive or negative, depending upon the nature of the dielectric (2). There are similar forces tending to move the dielectric bodily in such a way as to increase the integral value of  $\epsilon E^2$ , and if the dielectric is solid and if the field is produced by the charging of electrodes supported by it, then it will be subjected to the pressure arising from the mutual attraction of the electrodes. Deformations resulting from these two types of forces should not be classed as electrostrictive, although one or the other enters into many measurements of electrostriction.

Electrostrictive effects are generally derived from observations of the change in dimension of a condenser of which the dielectric is the substance to be studied (2, 14, 20, 50, 57, 63, 74, 75, 82, 96, 97, 127). If  $l$  is the dimension considered,  $\Delta l$  is the increase in  $l$  under action of the electric field, and if  $\mu$  is the corresponding elastic modulus, then  $\mu\Delta l/IE^2$  depends solely upon the configuration of the system, and upon  $\epsilon$  and its variation with  $\Delta l$ . The changes ( $\Delta l$ ) are very small and the sources of error are numerous; consequently the results obtained are frequently quite discordant and at times even qualitatively contradictory.

For summaries and discussions, *v.* (20, 50, 79, 81, 82); for recent developments, *v.* (2, 10, 14, 33, 34, 55, 57, 74, 75, 92.5, 123); for bibliography, *v.* (10, 100).

TABLE 1.—ELECTROSTRICTION

The following data are based upon the change in dimensions of a condenser when it is charged. This change frequently increases rapidly for several seconds; the values tabulated are presumably those approximately constant ones corresponding to an application of the field for 15 to 40 sec.

In column (2) the type of the condenser is indicated ( $c$  = cylindrical,  $s$  = spherical,  $p$  = plate) and the quantity corre-

<sup>1</sup> This section deals with data pertaining to electrostriction, piezoelectricity and pyroelectricity. All units are of the cgs system unless the contrary is stated.

sponding to  $l$  in the formula below is stated;  $c_s$  = cylindrical condenser with electrodes supported by the dielectric.

Röntgen (93) found that all liquids expanded under the action of  $E$ ; Quincke (81, 84) found that some contracted, the contraction for (C<sub>2</sub>H<sub>5</sub>)<sub>2</sub>O, almond oil, and rape oil being marked.

For air and CO<sub>2</sub>, Gans (35) found a reduction in pressure in an electric field, in rough agreement with the value predicted by theory. For other work with gases, *v.* (20, 50, 66, 82).

For other experimental work, *v.* (2, 20, 34, 35, 55, 57, 63, 66, 69, 70, 82, 96, 97, 127).

$\Delta l/IE^2 = A \times 10^{-7}$ . Unit of  $A \times 10^{-7} = 1 \text{ cm}^2 \text{ cgs}^{-2} = 1.113 \times 10^{-5} \text{ cm}^2 \text{ volt}^{-2}$ .

Dielectric	Condenser	A	n	Lit.
Glass* (1).....	$c_s$ , length	5.2	13	(10)
(2).....	$c_s$ , length	5.6	13	(10)
(3).....		1.3	13	(84)
(4).....		2.3	13	(84)
(5).....		5.7	13	(18)
(6).....		4.4	13	(19)
(7).....		7.1	13	(19)
(8).....	$s$ , volume	2.6†	7	(84)
Paraffin‡ (1).....	$c_s$ , length	8.4	11	(10)
(1).....	$c_s$ , length	9.4	11	(10)
Ebonite§.....	$c_s$ , length	5.8	12	(10)
		to		
		1.15	10	(10)
	$c$ , length	6.5	10	(10)
		1.0	9	(10)
Rubber   (1).....	$p$ , thickness	6.7	9	(10)
(2).....	$p$ , thickness	5.4	9	(10)
(3).....	$p$ , thickness	7.6	9	(10)

\* Values for (1) and (2) obtained 15 sec after application of  $E$ ; at 2 or 3 sec after application of  $E$ ,  $A$  is only 4. From data obtained (125, 126) with various glass tubes, electrodes not supported by the glass, Adams (2) deduces  $8\pi\mu\Delta l/IE^2 = -1.35$  to  $-3.78$ ; *v. also* (10, 57, 69, 70, 100).

† Flint glass.  $\Delta\epsilon/\epsilon E^2$  is unchanged by a variation of  $E$  in the ratio of 1 to 5.

‡ Values 35 to 40 sec after application of  $E$ ; at 5 sec after application of  $E$ ,  $A$  is only 4. Temperature, 24°C. Both recorded values are for same tube.

§ Various specimens of the  $c_s$  group have been treated so as to vary  $\mu$  ( $1.7 \times 10^9$  to  $27 \times 10^9$ ); the products of  $A \times 10^{-7}$  by the corresponding values of  $\mu$  are constant ( $\approx 0.18$ ). For the  $c$  group,  $\mu$  lay between  $1.3 \times 10^9$  and  $1.7 \times 10^9$ .

|| (1) and (2) are vulcanized "para-normal" rubber; (3) is unvulcanized pure rubber. The volume of the plate does not change when  $E$  is applied.



**Piezoelectricity.**—In general, when an anisotropic dielectric having no center of symmetry is mechanically strained, it becomes electrically polarized; the direction and magnitude of the polarization ( $P$ ) depend upon the nature of the crystal, upon the nature and amount of the strain and upon the direction of the strain with reference to the axes of the crystal. Conversely, when such a dielectric is subjected to an electric field ( $E$ ), not only are stresses of an electrostrictive nature set up in it, but also others which are usually much larger and which depend upon both the direction and magnitude of  $E$ . These effects are described as *piezoelectric*. The production of polarization by strain is called the *direct* effect; the other is the *converse* effect.

From experiments with calcite ( $\text{CaCO}_3$ ), dolomite ( $\text{CaMgC}_2\text{O}_6$ ), beryl ( $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ ), topaz ( $\text{Al}_2\text{F}_2\text{SiO}_4$ ), barite ( $\text{BaSO}_4$ ), and celestite ( $\text{SrSO}_4$ ), Voigt (120) concludes that crystals possessing a center of symmetry may possess "central-symmetrical" piezoelectricity. Also some investigators have observed what appears to be a piezoelectric effect for certain apparently non-crystalline substances such as beeswax and resin (3, 28), sheet rubber (12, 85), ebonite, glass, hornoid, sealing wax, celluloid and paraffin (12), but it is difficult to determine how much of the observed effect is due to frictional electricity and to the presence of very small piezoelectric crystals. The observations (85) lead to a value of the order  $10^{-5}$  for the strain-constant  $d$  for sheet rubber; this is nearly a thousand times as great as the value for most piezoelectric crystals.

If  $P_x, P_y, P_z$  are the components of the polarization (electric moment per unit of volume),  $E_x, E_y, E_z$ , the components of  $E$ ;  $x_x, y_y$ , etc., the six strain components;  $X_x, Y_y$ , etc., the six stress components; then

$$P_x = e_{11}x_x + e_{12}y_y + e_{13}z_z + e_{14}y_x + e_{15}z_x + e_{16}x_y \\ -P_x = d_{11}X_x + d_{12}Y_y + d_{13}Z_z + d_{14}Y_x + d_{15}Z_x + d_{16}X_y$$

The expressions for the components  $P_y, P_z$  are obtained from that for  $P_x$  by changing the first digit "1" of the subscript of each  $e$  to "2," and to "3," respectively:  $-P_y, -P_z$  are obtained from  $-P_x$  by changing similarly the subscripts of each  $d$ . For the converse effect:

$$x_x = d_{11}E_x + d_{21}E_y + d_{31}E_z \\ -X_x = e_{11}E_x + e_{21}E_y + e_{31}E_z$$

The other five equations of each set ( $y_y, z_z, y_x, z_x, x_y$ ; and  $Y_y, Z_z, X_y$ ) are obtained in order from these by changing the second digit (1) of the subscript of each  $d$  (or  $e$ ) to 2, 3, 4, 5, 6, respectively. The  $d$ 's and  $e$ 's are called the piezoelectric constants, the  $d$ 's being the *strain constants* and the  $e$ 's the *moduli*; they are mutually related by equations involving the elastic constants of the crystal (81, 82, 91, 117). Excepting triclinic asymmetric crystals, in each special case certain of these 18 parameters are necessarily zero. Those which may not be zero are indicated in Table 2.

When the polarization is parallel to the stress producing it, it is described as a longitudinal effect; it exists only when one or more of the constants with subscripts 11, 22, 33 are finite.

When the polarization is perpendicular to the direction of the strain producing it, it is described as a transverse effect; it exists whenever one or more of the constants with subscripts 12, 13, 21, 23, 31, or 32 are finite, and also for certain directions of the stress when one or more of the constants with subscripts 14, 25, 36 are finite; *v.* (15, 21, 25, 83, 117).

Owing to the smallness of the effect and to various sources of error such as twinning,<sup>1</sup> faulty orientation of crystal plate being studied, presence of impurities, etc., the data available are in most cases somewhat discordant. For many substances, our exact knowledge is limited to the fact that the piezoelectric constants are not all zero.

For full bibliography, including applications, *v.* (16); for recent

<sup>1</sup>Partially twinned crystals show a reduced piezoelectric effect; complete twinning removes the piezoelectric property altogether.

summary of information regarding piezo- and pyroelectricity, *v.* (36); for description of piezoelectric phenomena, general theory, and bibliography, *v.* (20, 21, 24, 81, 82, 91, 117); for more recent formulation of theory, *v.* (7, 9, 11, 37, 48, 99, 110, 111, 112); for applications to high-frequency circuits, *v.* (15, 17, 27, 38, 59, 67, 78, 98); for equations giving value of  $P$  for a pressure applied in an arbitrary direction, *v.* (82, 91, 103, 117); for representation of  $P$  by means of piezoelectric surfaces, *v.* (1, 4, 51, 91, 103, 117); for effect of hydrostatic pressure, *v.* (117); *cf.* (56); for discussion of second-order effects, *v.* (82, 117, 119).

A list of crystals for which piezoelectric effects have been observed, and their constants, are given in Table 3.

TABLE 2.—THE PIEZOELECTRIC CONSTANTS PRESENT FOR EACH CLASS OF CRYSTALS POSSESSING THE PIEZOELECTRIC PROPERTY

Excepting the plagioclinal cubic class (117), all of the 21 classes of crystals having no center of symmetry are piezoelectric.

The parameters are denoted by their subscripts in accordance with the scheme of equations. A repetition of a subscript for any crystal class indicates that for this class the corresponding parameters have the same value. In writing the equations for the five trigonal classes, a factor 2 must precede each  $d$  corresponding to parameters 16 and 26, in all other cases the equations are written as above, those parameters corresponding to blanks in the table being necessarily zero.

Hex. = hexagonal, Rho. = rhombic, Mon. = monoclinic,  
P = polar

The coordinate axes are assumed to be orthogonal, to form a right-handed system, and to be directed as indicated in the footnotes.

True polar pyroelectric effects (p. 209) may be exhibited by classes 2, 4, 6, 9, 12, 14, 15, 17, 18, 19; for class 19,  $P_x, P_y$ , and  $P_z$  are all present; for 18, only  $P_x$  and  $P_y$  are present; for all the other classes, only  $P_z$  exists.

Class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
	Hex.*			Trigonal†					Tetragonal‡					Rho.‡		Mon.§				
Polarization	Parameter	Cubic	Polar	Trapezohedral	Tripyramidal polar	Holohedral	Polar	Trapezohedral	Tetartohedral	Tetartohedral polar	Polar	Trapezohedral	Tripyramidal polar	Sphenoidal	Tetartohedral	Polar	Sphenoidal	Polar	Clinohedral	Triclinic¶ asymmetric
$P_x$	11					11		11	11	11									11	11
	12					-11		-11	-11	-11									12	12
	13																		13	13
	14	14		14	14			14		14	14	14	14	14			14	14		14
	15		15		15		15			15	15				15	15		15		15
	16					-22		-22	-22										16	16
$P_y$	21						-22	-22	-22										21	21
	22						22	22	22										22	22
	23																		23	23
	24		15		15		15		15	-15		15		15	24		24		24	24
	25	14		-14	-14		-14		-14	14	-14	-14	14			25	25		25	25
	26					-11		-11	-11										26	26
$P_z$	31	31		31		31			31	31		31		31	31		31		31	31
	32	31		31		31			31	-31		31		31	32		32		32	32
	33	33		33		33			33			33		33	33		33		33	33
	34																		34	34
	35																		35	35
	36	14								36			36			36	36		36	36

\*  $z$ -axis coincides with the  $c$ -axis of 6-fold symmetry; where polar, the + direction is direction of the polarization produced by heating the crystal. The  $y$ -axis is  $\perp$  to a face of the first order prism.

†  $z$ -axis coincides with the  $c$ -axis of 3-fold symmetry. The  $y$ -axis and the + direction of the  $z$ -axis are as for hexagonal (\*). Polarization of class 7 is not changed by hydrostatic pressure.

‡ Coordinate axes  $x, y, z$  coincide, respectively, with crystallographic axes  $a, b, c$ .

§  $z$ -axis  $\parallel c$ -axis;  $x$ -axis  $\parallel b$ -axis;  $y$ -axis lies in obtuse angle between the  $a$ - and  $c$ -axes.

|| Only the tetragonal (1a) and the tetartohedral (1a) classes are piezoelectric.

¶ Only the asymmetric class is piezoelectric. No convention regarding directions of axes of coordinates.



**Pyroelectricity.**—The electrical polarization ( $P$ ) of many substances is changed when the temperature of the substance is changed; this phenomenon is described as *pyroelectric*.  $\delta P/\delta t$  is called the pyroelectric constant of the substance; it decreases with the temperature and perhaps vanishes at absolute zero.

Several types of pyroelectricity are distinguished. The most marked pyroelectric effects are exhibited by those crystals which have a vectorial (polar) structure defining, not merely a line, but a definite direction along that line. The type exhibited by such crystals is called the *polar* or *vectorial* type of pyroelectricity; it is the type commonly associated with the word "pyroelectric." This type can be exhibited only by crystals belonging to the classes 2, 4, 6, 9, 12, 14, 15, 17, 18, and 19 of Table 2. Another type, in which the effects are much smaller, is known as the *central* or *tensorial* type; it may be exhibited (82, 91, 116, 117, 120, 121) by changing uniformly the temperature of crystals which have a certain type of tensorial symmetry; this type of symmetry occurs in every crystal class except those of the cubic system.

As crystals which are pyroelectric are also piezoelectric, the deformations accompanying changes in temperature give rise to polarizations of piezoelectric origin. These *false* pyroelectric effects are superposed upon the *true* pyroelectric effects which result solely from changes of temperature, effects due to accompanying strain being eliminated. In general, any piezoelectric crystal, when deformed by a change in temperature, whether uniform or not, exhibits false pyroelectric effects. Those produced by non-uniform heating are the more common and are called the false pyroelectric effects of the first kind, those produced by uniform heating being called the false effects of the second kind. As the false effects are generally much greater than the true, it is difficult to determine the latter. Indeed, the true pyroelectric effect has been investigated only for tourmaline and its existence for that substance is questioned. The magnitude of the pyro effect observed depends markedly upon both the surface and the volume conductivity of the specimen (61, 94, 114, 117).

The converse, or "electro-caloric," effect (the change in temperature resulting from the application of an electric field) has been detected (58, 102, 117).

For general discussion of pyroelectricity, *v.* (20, 41, 60, 81, 82, 83, 91, 117); for its molecular theory, *v.* (6, 7, 8, 20, 82, 83, 91,

110, 112, 117); most complete quantitative data are by Ackermann (1), discussed by Boguslawski (6).

For data for specific substances, see Table 3.

In addition to the substances tabulated below, both pyro and piezo effects have been observed (23, 30, 82, 91, 117, 120, 121) in the following crystals possessing a center of symmetry: topaz ( $\text{Al}_2\text{F}_2\text{SiO}_4$ ), barite ( $\text{BaSO}_4$ ), beryl ( $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ ), calcite ( $\text{CaCO}_3$ ), dolomite ( $\text{CaMgC}_2\text{O}_6$ ) and celestite ( $\text{SrSO}_4$ ); and by means of a high frequency method, in which the orientation of the axes of the crystal could not be determined, traces of the piezoelectric effect have been found (38) in the following crystals: proustite ( $\text{Ag}_3\text{AsS}_3$ ), urea ( $\text{CH}_4\text{N}_2\text{O}$ ), ammonium oxalate ( $\text{N}_2\text{H}_8\text{C}_2\text{O}_4$ ), asparagine ( $\text{C}_4\text{H}_8\text{N}_2\text{O}_3\cdot\text{H}_2\text{O}$ ), ammonium acid tartrate ( $\text{NH}_4\text{HC}_4\text{H}_4\text{O}_6$ ), pentaerythritol ( $\text{C}_5\text{H}_{12}\text{O}_4$ ), tetraethylammonium iodide ( $\text{N}(\text{C}_2\text{H}_5)_4\text{I}$ ), triphenylmethane ( $\text{CH}(\text{C}_6\text{H}_5)_3$ ), potassium acid tartrate ( $\text{KHC}_4\text{H}_4\text{O}_6$ ), magnesium sulfate ( $\text{MgSO}_4\cdot 7\text{H}_2\text{O}$ ), ammonium acid phosphate ( $\text{NH}_4\text{H}_2\text{PO}_4$ ), sodium tartrate ( $\text{Na}_2\text{C}_4\text{H}_4\text{O}_6$ ), sodium sulfoantimonate ( $\text{Na}_3\text{S}_4\text{Sb}\cdot 9\text{H}_2\text{O}$ ), nickel sulfate ( $\text{NiSO}_4\cdot 6\text{H}_2\text{O}$ ) and zinc sulfate ( $\text{ZnSO}_4\cdot 7\text{H}_2\text{O}$ ). For other crystals, *v.* (43, 43.5, 44, 45, 46, 49, 64, 65, 68). For piezoelectric effects with apparently non-crystalline substances, *v.* p. 208.

No observation of either kind of effect was found recorded for crystals of classes 3, 5, 8, 10, 11, 13, 14 (*v.* Table 2). Of the other classes, no direct piezo observation was found recorded for classes 2, 4, 9, 12, 15, 18, 19, but all crystals which exhibit pyro effects are also piezoelectric. Crystals of class 7 are not excited by hydrostatic pressure.

The numbers in the column "C. S." indicate the crystal class of the substance, in accordance with the numbers of Table 2. The presence of the mark "✓" in a column indicates that the corresponding effect has been actually observed, but the numerical value of the constant is not known with certainty; if the detected pyro effect is necessarily a "false" one, the "✓" is replaced by an "f;" blanks indicate that no record of observations was found. In column "C" is the symbol indicating the piezoelectric strain constant which has the value  $A \times 10^{-8}$ ,  $A$  being the value adjacent to the symbol. For example, for tourmaline at room temperature,  $d_{33} = 5.78 \times 10^{-8}$  (es/cm<sup>2</sup>)/(dyne/cm<sup>2</sup>). Units are cgse. Data for pyro effect refer to the total effect, the sum of the "true" and the "false."

TABLE 3.—A LIST OF SUBSTANCES FOR WHICH EITHER PIEZO- OR PYROELECTRIC EFFECTS HAVE BEEN OBSERVED; TOGETHER WITH THEIR CONSTANTS AT ROOM TEMPERATURE

Formula	Substance	C. S.	Pyro		Piezo		
			$\delta P/\delta t$	Lit.	C	A	Lit.
Variable	Tourmaline ( <i>v.</i> Table 4).....	6	$\left\{ \begin{array}{l} 1.1 \\ 1.3 \end{array} \right\}$	(1)	$d_{33}$	5.78	(89, 115)
$\text{Ba}(\text{CHO}_2)_2$	Barium formate.....	16	f	(45)			(45)
$\text{Ba}(\text{SbO})_2(\text{C}_4\text{H}_4\text{O}_6)_2\cdot\text{H}_2\text{O}$	Barium antimonyl tartrate.....	12	✓	(104, 113)			(81, 113)
$(\text{Be, Mn, Fe})_7\text{Si}_2\text{O}_{12}\text{S}$	Helvite.....	1 <sub>a</sub>	f	(43, 43.5)			(43, 43.5)
C	Diamond.....	1 <sub>a</sub>	0.0*	(113)		0†	(113)
$\text{C}_2\text{H}_5\text{N}_4\text{O}_4$	Methylene diisonitramine methyl ester $\text{CH}_2(\text{N}_2\text{O}_2\cdot\text{CH}_3)_2$ .....	15	✓	(81, 109)			
$\text{C}_4\text{H}_6\text{O}_6$	Tartaric acid.....	17	7.5	(47)	$d_{33}\ddagger$	6.4	(103)
$\text{C}_4\text{H}_{12}\text{N}_2\text{O}_6$	Ammonium tartrate.....	17	2.84§	(1, 47)			(38)
$\text{C}_6\text{H}_5\text{N}_3\text{O}_7$	Picric acid.....	15	✓	(13)			
$\text{C}_6\text{H}_6\text{O}_2$	Resorcinol.....	15	7.7	(47)			(38)
$\text{C}_6\text{H}_{12}\text{O}_6$	Quercitol.....	17	✓	(81)			
$\text{C}_6\text{H}_{12}\text{O}_5\cdot\text{H}_2\text{O}$	<i>d</i> -Rhamnose (isodulcitol).....	17	$\left\{ \begin{array}{l} 3.63 \\ 0.505 \end{array} \right\}$	(47)			
$\text{C}_6\text{H}_{15}\text{ClN}$	Triethylamine hydrochloride.....	2	✓	(42)			
$\text{C}_7\text{H}_7\text{BrO}_4$	Bromoshikimilactone.....	4	✓	(107)			
$\text{C}_{10}\text{H}_{15}\text{NO}$	Carvoxime $\text{C}_{10}\text{H}_{14}\cdot\text{NOH}$ .....	17	✓	(81)			
$\text{C}_{10}\text{H}_{13}\text{Br}_5\text{O}$	Carvone pentabromide.....	17	✓	(122)			

\* Value is relative to tourmaline (kind not specified) as unity. † No trace of piezoelectricity. ‡ *v.* Table 7.



TABLE 3.—(Continued)

Formula	Substance	C. S.	Pyro		Piezo		
			$\delta P/\delta t$	Lit.	C	A	Lit
$C_{10}H_{17}NO$	Fenchoneoxime.....	17	✓	(81)			
$C_{12}H_{22}O_{11}$	Saccharose (cane sugar).....	17	0.53	(47)	$d_{33}\dagger$	-10.2	(51)
$C_{12}H_{22}O_{11} \cdot H_2O$	Lactose.....	17	✓	(81)			
$C_{14}H_{10}O_2$	Benzil.....	7			$d_{11}$	24	(113)
$C_{14}H_{12}O$	Phenyl <i>p</i> -tolyl ketone $C_6H_5.CO.C_6H_4.CH_3$ .....	6	✓	(5)			
$C_{15}H_{26}O$	Patchouli camphor.....	7(?)			$d_{11}$	0.14	(113)
$CaAl_2Si_3O_{10} \cdot 3H_2O$	Scolecite.....	18	0.99	(47)			
$2CaO \cdot Al_2O_3 \cdot 3SiO_2 \cdot H_2O$	Prehnite.....	15	✓	(92, 108)			
$3Ca_3P_2O_8 \cdot CaF_2$	Fluoroapatite.....	4	✓	(44)			
$K_2C_4H_4O_6 \cdot \frac{1}{2}H_2O$	Potassium tartrate.....	17	5.96§	(1, 47)			(38)
$KBrO_3$	Potassium bromate.....	6	✓	(107)			
$K_2S_2O_8$	Potassium dithionate.....	7	f	(46)			(46)
$KLiSO_4$	Potassium lithium sulfate.....	4	4.86§	(1, 47)			
$(KLiSO_4)_x + (KLiCrO_4)$	Mixture.....	4	✓	(105)			
$(KLiSO_4)_{18} + KLiMoO_4$	Mixture.....	4	✓	(105)			
$K_2SO_4 + Li_2CrO_4$	Mixture.....	4	✓	(105)			
$KLiSeO_4$	Potassium lithium selenate.....	4	✓	(105)			
$KNaC_4H_4O_6 \cdot 4H_2O$	Rochelle salt ( <i>v.</i> Table 6).....	16	✓	(110, 111, 112)	$d_{14}$ $d_{14}$	340 to 1180 8100	(80) (111)
$Li_2SO_4 \cdot H_2O$	Lithium sulfate.....	17	23.2§	(1, 47)			(38)
$Li_2SeO_4 \cdot H_2O$	Lithium selenate.....	17	17.17§	(1, 47)			
$LiNa_3(MoO_4)_2 \cdot 6H_2O$	Lithium trisodium molybdate.....	6	✓	(113)	$d_{33}$	14	(113)
$LiNaSO_4$ (anhydrous)	Lithium sodium sulfate.....	6	2.3§	(1, 47)			
$LiNa_3(SeO_4)_2 \cdot 6H_2O$	Lithium trisodium selenate.....	6	5.38§	(1, 47)			
$6MgO \cdot 8B_2O_3 \cdot MgCl_2$	Boracite  .....	1a	0.07*	(32, 113)			(23, 24, 113)
$NaBrO_3$	Sodium bromate.....	1b	f	(46)			(46)
$NaClO_3$	Sodium chlorate.....	1b	f	(23, 31, 32, 46)	$d_{14}$	-4.8	(80); <i>cf.</i> (23, 32, 46)
$NaIO_4 \cdot 3H_2O$	Sodium periodate.....	9	✓	(46)			
$Pb(CHO_2)_2$	Lead formate.....	16	f	(45)			(45)
$Pb(SbO.C_4H_4O_6)_2$	Lead antimonyl tartrate.....	4	✓	(106)			
$Rb_2C_4H_4O_6$	Rubidium tartrate.....	7			$d_{11}$	8.2	(113)
$SiO_2$	Quartz ( <i>v.</i> Table 5).....	7	0.50f*	(31, 113)	$d_{11}$	-6.9	(22, 95)
$Sr(CHO_2)_2$	Strontium formate.....	16	f	(45)			(45)
$Sr(HC_4H_4O_6)_2 \cdot 4H_2O$	Strontium acid tartrate.....	19	$\left\{ \begin{array}{l} 0.73\ddagger \\ 6.7^* \end{array} \right\}$	(1, 47, 113)			
$Sr(SbO.C_4H_4O_6)_2$	Strontium antimonyl tartrate.....	4	✓	(106)			
$SrS_2O_8 \cdot 4H_2O$	Strontium dithionate.....	7	f	(46)			(46)
$2ZnO \cdot SiO_2 \cdot H_2O$	Calamine (hemimorphite).....	15	5.0*	(113); <i>cf.</i> (23)			
$ZnS(\beta)$	Sphalerite.....	1a	0.13*	(30, 32, 113)	$d_{11}$	4.8	(113)

§ *v.* Table 8. || Isotropic if  $t > 265^\circ C$ . ¶ For pressure along an axis of 3-fold symmetry; the resulting polarization is in same direction.

TABLE 4.—TOURMALINE: PYRO- AND PIEZOELECTRIC CONSTANTS

The *z*-axis coincides with the ternary (optical) axis of the crystal, and the *x*-axis lies in any one of the three planes of trigonal symmetry. The positive direction of *z* passes through the end of the crystal which becomes charged positively when the crystal is uniformly heated. This end is called the "analogous" end of the crystal; frequently it is not possible, by mere inspection, to determine which is the analogous end (124). The opposite end is called the antilogous end. The values found for the constants vary considerably from one specimen to another; in general, those for the darker specimens are the smaller in numerical value. The permanent electrical polarization along the *z*-axis is about  $8 \times 10^4$  cgse (87, 90, 91); hydrostatic pressure increases it about  $8 \times 10^{-8}$

cgse per barye (56). Whether tourmaline exhibits "true" pyroelectric effects is doubtful; Voigt (114, 117) thought the true effect amounted to 20% of the total, but Röntgen (94, 118) and Lindmann (61) decided that it is too small to measure. The values given below represent the total pyroelectric effect. Writing  $\delta P/\delta t = a + 2b(t - t_0)$ , where *P* = the polarization along the *z*-axis, and *t* and *t*<sub>0</sub> are final and initial temperatures, values of *a* varying, with the specimen, from 0.52 to 2.03, and of *b* varying from -0.000256 to +0.0117 were found (88, 91); experiments extended to *t* = 160°C. For pyroelectric data, *v.* (1, 81, 83, 91, 113, 117); for piezoelectric, *v.* (81, 89, 91, 114, 115, 117, 120). *P* = polarization, *T* = absolute temperature,  $A_{15} \times 10^{-4} = d_{15}$ , etc.;  $B_{15} \times 10^4 = e_{15}$ , etc. (*v.* p. 208). Unit of *T* = 1°K; of *P*, *d*, *e* = 1 cgse unit of appropriate kind.



Pyroelectric  $\delta P/\delta T$ 

$T$	B. G.*	Y. G.*	R. R.*
23	0.04	0.08	0.08
88	0.142	0.289	0.300
198	0.652	0.974	0.982
253	0.935	1.205	1.219
274	1.005	1.243	1.270
293	1.060	1.281	1.313
(293)	1.057†	1.275†	1.324†
352	1.170	1.337	1.404
372	1.187	1.350	1.426
408	1.217	1.381	1.460
488	1.268	1.490	1.544
578	1.381	1.669	1.723
648	1.525	1.865	1.943

L. G.† (94)

$T$ .....	20.5	79	194	273	313.5	291
$\delta P/\delta T$ .....	0.037	0.20	0.66	0.96	1.10	1.13§

Piezoelectric Constants||

$A_{16}$ .....	11.04				$B_{15}$ .....	7.40
$A_{22}$ .....	-0.69	-0.94			$B_{22}$ .....	-0.53
$A_{31}$ .....	0.74	0.96			$B_{31}$ .....	3.09
$A_{33}$ .....	5.78	5.4	5.4	5.6	$B_{33}$ .....	9.60
Lit.....	(89, 115)	(94)	(113)	(71)	Lit.....	(89, 115)

\* B. G. = blue-green, Y. G. = yellow-green, R. R. = rose-red. Data from (1).

† Data from (47).

‡ L. G. = light-green, data from (94). With darker specimens he found values only 83 % of these; discussed in (118).

§ From (86) for 5 green Brazilian specimens:  $\delta P/\delta T = 1.13-0.0104(T - 291)$ .

|| Vary but little with changes in pressure and temperature; between 20°C and the temperature of liquid air (62) and for pressures up to 22 megabarye (71), the variation of  $d_{11}$  lies within the limits of experimental error. From theoretical considerations, Keys (54) concludes that, for tourmaline, the adiabatic piezoelectric constants, corresponding to suddenly applied stress, are 1.5 times as great as the usual isothermal ones.  $d_{11} = A_{11} \times 10^{-8}$ , etc.;  $e_{11} = B_{11} \times 10^4$ , etc.

TABLE 5.—QUARTZ: PYRO- AND PIEZOELECTRIC CONSTANTS

For information regarding all properties of  $\text{SiO}_2$ , *v.* (101)

The  $z$ -axis coincides with the crystallographic  $c$ -axis of 3-fold symmetry, the  $y$ -axis is  $\perp$  to a face of the hexagonal first order prism, and, in dextro crystals, the  $+$  direction of the  $x$ -axis is outward through one of the faces (commonly denoted by  $s$ ) of the trigonal pyramid; in levo crystals, the direction of the  $x$ -axis with reference to the  $s$ -faces is reversed; in each case, the  $+$  direction of the  $y$ -axis is such as to form a right-handed system of orthogonal axes. At 573°C, ordinary  $\text{SiO}_2$  (trigonal, trapezohedral), known as " $\alpha$ -quartz," becomes transformed to " $\beta$ -quartz" (hexagonal, trapezohedral) and loses its pyro- and piezoelectric properties (11, 37, 77, 101). Owing to its crystal form,  $\text{SiO}_2$  can have no "true" pyroelectric properties;  $\delta P/\delta t$  is approximately proportional to the absolute temperature (73), and at room temperature is about half as great as the value for tourmaline (113). Twinning is common; dextro and levo crystals have equally strong electrical properties; hence, specimens which are completely twinned are not piezoelectric.

Quartz is not electrically excited by hydrostatic pressure. The value of  $d_{11}$  is probably unchanged by pressure parallel to  $x$ -axis; Nachtikal (71) found it to decrease by 0.16% per megabarye, but Röntgen and Joffé (95) found it was not changed by 0.4% by a pressure of 18 megabarye, and according to Karcher (53) it remains constant to within 0.1% for pressures  $\leq 3450$  megabarye.

At room temperatures  $d_{11}$  is practically independent of temperature. There is some evidence that it increases by about 20% as  $t$  goes from room temperature to 60°C, and then with a further increase in  $t$  it gradually decreases until at 573°C it vanishes (26.5, 79, 82, 86, 101). On cooling it reappears. On cooling from +17 to -193°C,  $d_{11}$  decreases by 1.2%; cooling from -193 to -253°C causes a change of less than 0.2% (73). Ze (127) reports that the piezoelectric deformation of quartz reaches a saturation value at a field intensity of about 520 cgse units. In the following, the best values are printed in bold-face. Unit of  $d_{11}$  and  $d_{14} = 10^{-8}$  cgse; of  $e_{11}$  and  $e_{14} = 10^4$  cgse.

$d_{11}$ .....	-6.32	-6.3	-6.45	-6.27	-6.54	-6.3	-6.31	-6.90
Lit.....	(21,25)	(26)	(89)	(80)	(71)	(113)	(47)	(22)
$d_{11}$ .....	-6.94	-6.4	$d_{14}$ .....	+1.7	+1.45	+1.93	$e_{11} = -5.10$	
Lit.....	(95)	(127)	Lit.....	(101)	(89)	(80)	$e_{14} = -1.35$	

**Piezoelectric Resonators.**—From the density ( $2.654 \text{ g cm}^{-3}$ ) and the elastic constants (117) of quartz, the natural frequencies ( $\nu$ ) of compressional vibrations parallel to the edges of a quartz parallelepiped cut with its edges  $a$ ,  $b$ ,  $c$  parallel to the crystal axes  $x$ ,  $y$ ,  $z$ , are  $\nu_x = 2.70 \times 10^5/a$ ,  $\nu_y = 2.70 \times 10^5/b$ , and  $\nu_z = 3.08 \times 10^5/c$  cycle per sec if the lengths of the edges are  $a$  cm,  $b$  cm, and  $c$  cm. In each case the wave-length of the elastic wave in the crystal is twice that of the corresponding edge. Through the agency of  $d_{11}$ , the vibrations along  $x$  and  $y$  may be directly excited by a high-frequency electric field applied parallel to  $x$ . Also, through the same  $d_{11}$ , a transverse, or shear, mode of vibration may be excited by a high-frequency field parallel to  $y$ , the fundamental frequency being  $\nu_{xy} = 1.79 \times 10^5/b$  cycle per sec. This vibration depends upon the rigidity of quartz for torsion about the  $z$ -axis. In all of these values for the frequency the effect of sectional area is ignored, but the computed frequencies agree fairly well with those observed; *v. also* (16, 26, 81, 95, 117).

TABLE 6.—ROCHELLE SALT ( $\text{KNaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$ ): PYRO- AND PIEZOELECTRIC CONSTANTS

Axes  $x$ ,  $y$ ,  $z$  coincide, respectively, with crystallographic axes  $a$ ,  $b$ ,  $c$ . Electrical properties are complicated and are greatly affected by changes in temperature and humidity, and by the past history of the specimen; great differences between individual specimens (29, 52, 72, 110, 111, 112). Valasek (110, 111, 112) thinks it has "true" pyroelectric properties although the crystal form indicates that they can not exist; his computations (110) indicate a permanent electrical polarization of the order of 50 cgse units; *v. also* (23). Rochelle salt (potassium sodium tartrate) is not electrically excited by hydrostatic pressure; its  $d_{14}$  is the largest known piezoelectric constant; *v. especially* (72). Unit of  $d_{14}$ ,  $d_{25}$ , and  $d_{36} = 10^{-8}$  cgse. Note: In other tables the unit, or common factor, is  $10^{-8}$ .

$t$ .....	-70	-50	-30	-20	-10	0	10	20	30	40	°C
$d_{14}$ .....	0.17	0.17	0.65	10.8	60.7	67.5	74.2	81.0	10.8	4.1	(112)

The maximum is much greater than that recorded by any other observer. Later observations (112.5) indicate that with increasing  $t$ ,  $d_{14}$  increases rapidly from a very low value to about 23 at -20°C, increases slightly from -20 to +25°C, and then decreases rapidly. Between -60 and +30°,  $d_{25}$  and  $d_{36}$  increase linearly with  $t$ , their rates being, respectively,  $6.8 \times 10^{-9}$  and  $3.1 \times 10^{-10}$  cgse unit per 1°C (112.5).

Near 20°C, Pockels (80) finds  $d_{14} = 3.40$  to 11.80;  $d_{25} = -1.65$ , and  $d_{36} = 0.35$ .

From these data and the elastic constants (66.5) it is found that  $e_{14} = 56 \times 10^4$  to  $194 \times 10^4$ ,  $e_{25} = -5.33 \times 10^4$ , and  $e_{36} = 4.34 \times 10^4$  cgse units.



From the density ( $1.767 \text{ g cm}^{-3}$ ) and the elastic constants (66.5) the velocity of compressional waves in a bar of Rochelle salt cut with its length perpendicular to the  $x$ -axis and at  $45^\circ$  with the  $y$  and  $z$  axes is found to be  $3.98 \times 10^5 \text{ cm/sec}$ . Hence, natural frequency ( $\nu$ ) of such vibrations in a bar  $a \text{ cm}$  long is  $1.99 \times 10^5/a$  cycle per sec; experimental values may be expected to differ rather widely from this value (17).

TABLE 7.—PIEZOELECTRIC CONSTANTS OF TARTARIC ACID ( $\text{C}_4\text{H}_6\text{O}_6$ ) AND OF CANE SUGAR ( $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ )

Room temperature; precision about 3%; system = monoclinic polar.  $d_{14} = A_{14} \times 10^{-8}$ ; etc. Unit of  $d = 1 \text{ cgse}$ .

Formula	$A_{11}$	$A_{12}$	$A_{13}$	$A_{21}$	$A_{22}$	$A_{23}$	$A_{31}$	$A_{32}$	Lit.
$\text{C}_4\text{H}_6\text{O}_6$ .....	-24	28.3	28.5	-36.5	1.95	5.9	6.4	3.8	(103)
$\text{C}_{12}\text{H}_{22}\text{O}_{11}$ .....	1.27	-12.6	-7.2	3.75	2.21	4.4	-10.2	-2.62	(51)

TABLE 8.—PYROELECTRIC EFFECT: VARIATION WITH TEMPERATURE (1)

$T$  = absolute temperature,  $^\circ\text{K}$ . Unit of  $\delta P/\delta t = 1 \text{ cgse unit}$

$T$	23	88	198	253	274	293	293*	352
Formula	$\delta P/\delta t$							
$\text{Sr}(\text{HC}_4\text{H}_4\text{O}_6)_2 \cdot 4\text{H}_2\text{O}^\dagger$ .....	0.04	0.12	0.45	0.64	0.69	0.728	0.73	0.825
$\text{NaLiSO}_4$ .....	0.12	0.29	0.88	1.63	2.03	2.26	2.31	2.74
$\text{C}_4\text{H}_{12}\text{N}_2\text{O}_6^\ddagger$ .....	0.15	0.31	1.18	2.41	2.58	2.84	2.84	3.42
$\text{KLiSO}_4$ .....		0.69	2.50	4.09	4.51	4.85	4.88	5.35
$\text{Na}_3\text{Li}(\text{SeO}_4)_2 \cdot 6\text{H}_2\text{O}$ .....	0.35	0.93	2.94	4.58	5.07	5.38	5.38	6.37
$\text{K}_2\text{C}_4\text{H}_4\text{O}_6 \cdot \frac{1}{2}\text{H}_2\text{O}^\dagger$ .....	0.39	1.00	3.32	5.10	5.60	5.96	5.98	6.89
$\text{Li}_2\text{SeO}_4 \cdot \text{H}_2\text{O}$ .....	0.92	2.30	9.87	14.54	16.00	17.17	17.14	19.35
$\text{Li}_2\text{SO}_4 \cdot \text{H}_2\text{O}$ .....	1.21	3.81	12.24	18.42	20.45	23.27	23.18	26.90

\* (47).  $^\dagger$  Tartrate.  $^\ddagger$  Ammonium tartrate.

## LITERATURE

(For a key to the periodicals see end of volume)

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## THERMOELECTRICITY

A. E. CASWELL

CONTENTS	MATIERES	INHALTSVERZEICHNIS	INDICE	PAGE
Thermo emf and thermoelectric power of elementary substances.	Thermo-fem et pouvoir thermoélectrique des substances élémentaires.	Thermoelektromotorische Kraft und thermoelektrische Kraft elementarer Stoffe.	Fem termica e potere termoelettrico di elementi.	214
Thermoelectric power of couples of pure Fe and Pt.	Pouvoir thermoélectrique des couples de Fe pur et Pt.	Thermoelektrische Kraft von Paaren mit reinem Fe und Pt.	Potere termoelettrico di coppie di ferro e platino puri.	215
Thermoelectric power and thermo emf: alloys.	Pouvoir thermoélectrique et thermo-fem: alliages.	Thermoelektrische Kraft und thermoelektromotorische Kraft: Legierungen.	Potere termoelettrico e fem termica: leghe.	215
Thermoelectric power: steels.	Pouvoir thermoélectrique: aciers.	Thermoelektrische Kraft: Stähle.	Potere termoelettrico: acciai.	222
Thermo emf: carbon steels.	Thermo-fem: aciers au carbone.	Thermoelektromotorische Kraft: Kohlenstoffstähle.	Fem termica: acciai al carbonio.	224
Thermoelectric power: oxides and sulfides.	Pouvoir thermoélectrique: oxydes et sulfures.	Thermoelektrische Kraft: Oxyde und Sulfide.	Potere termoelettrico: ossidi e solfuri.	224
Effect of stress upon thermoelectric properties: metals.	Effet de la tension sur les propriétés thermoélectriques: métaux.	Einfluss mechanischer Kräfte auf die thermoelektrischen Eigenschaften: Metalle.	Azione di uno sforzo sopra le proprietà termoelettriche: metalli.	225
Effect of stress upon thermoelectrical properties of Al, Fe, and Sn.	Effet de la tension sur les propriétés thermoélectriques de Al, Fe et Sn.	Einfluss mechanischer Kräfte auf die thermoelektrischen Eigenschaften des Al, Fe und Sn.	Azione di uno sforzo sopra le proprietà termoelettriche di Al, Fe, Sn.	226
Effect of longitudinal magnetic field and of tension upon thermoelectric properties of metals.	Effet d'un champ magnétique longitudinal et de la tension sur les propriétés thermoélectriques des métaux.	Einfluss des longitudinalen magnetischen Feldes und der Dehnung auf die thermoelektrischen Eigenschaften der Metalle.	Effetto di un campo magnetico longitudinale e della tensione sopra le proprietà termoelettriche dei metalli.	226
Effect of magnetic field and of tension upon thermo emf of bimetallic circuits.	Effet du champ magnétique et de la tension sur la thermo-fem des circuits bimétalliques.	Einfluss des magnetischen Feldes und des Druckes auf die thermoelektromotorische Kraft bimetallicher Systeme.	Effetto del campo magnetico e delle tensioni sopra la fem termica di circuiti bimetallici.	226
Peltier coefficient: directly observed.	Coefficient de Peltier: directement observé.	Peltier-Koeffizient: direkt beobachtet.	Coefficiente di Peltier: osservato direttamente.	227
Peltier coefficient: directly observed variation with temperature.	Coefficient de Peltier: variation avec la température directement observée.	Peltier-Koeffizient: direkt beobachtet Änderung mit der Temperatur.	Coefficiente di Peltier: variazione con la temperatura osservata direttamente.	228
Peltier coefficient of bismuth: directly observed effect of a magnetic field.	Coefficient de Peltier du bismuth: effet du champ magnétique directement observé.	Peltier-Koeffizient des Wismuts: direkt beobachteter Effekt eines magnetischen Feldes.	Coefficiente di Peltier nel bismuto: osservazione diretta dell'effetto di un campo magnetico.	228
Thomson coefficient: directly observed.	Coefficient de Thomson: directement observé.	Thomson-Koeffizient: direkt beobachtet.	Coefficiente di Thomson: direttamente osservato.	228

If two metallic conductors,  $M$  and  $R$ , are connected in series so as to form a closed circuit, and if one junction is kept at the temperature,  $0^\circ\text{C}$  and the other at the temperature,  $t$  ( $t \neq 0$ ), there will be a thermo emf  ${}_ME_R$  around the circuit. By convention,  ${}_ME_R$  is regarded as positive if the current so produced flows from  $M$  to  $R$  at the junction which is at  $0^\circ\text{C}$ .  ${}_RE_M = -{}_ME_R$ ;  ${}_ME_R + {}_RE_S = {}_MES$ .  ${}_MQ_R \equiv \partial {}_ME_R / \partial t$  is called the thermoelectric power of  $M$  with respect to  $R$ . As a current  $I$  passes through a junction from  $R$  to  $M$  an amount of heat  $({}_MP_R)I = T({}_MQ_R)I$  is absorbed per second;  ${}_MP_R$  is the Peltier coefficient of  $M$  with respect to  $R$ , and  $T$  is the absolute temperature corresponding to  $t$ . If  ${}_MQ_R$  is negative, so is  ${}_MP_R$ , and heat is evolved when current flows from  $R$  to  $M$ . The equations are valid for any consistent system of units; in particular, if  $E$  is expressed in volts and  $I$  in amperes, the heat is expressed in joules. If, in an unequally heated homogeneous conductor, a current,  $I$ , flows from a point where the temperature is  $t_2$  to another where it is  $t_1$ ,  $t_2 > t_1$ , an amount of

heat  $H = \int_{t_1}^{t_2} I \sigma dt$  will be absorbed per second, apart from the usual Joule heating effect.  $\sigma$  is the Thomson coefficient of the metal in question; it may be either positive or negative. Denoting by a subscript the metal to which  $\sigma$  refers,  $\sigma_M - \sigma_R = -T(\partial^2 {}_ME_R / \partial t^2)$ .

All four quantities,  ${}_ME_R$ ,  ${}_MQ_R$ ,  ${}_MP_R$  and  $\sigma_M$  are profoundly affected by anything which alters the structure of the metals to which they refer. They are greatly affected by impurities, heat treatment, drawing, rolling, pressure, tension and magnetization. Only very rarely will identical thermoelectric curves be found for two couples formed from the same pair of metals.

For a bar cut from a crystal, the value of  $Q$  will, in general, depend upon the direction which the length of the bar makes with the axis of the crystal. When  $Q$  does depend upon this direction, the bar, unless cut parallel to one of the principal thermoelectric axes, exhibits another distinct thermoelectric property, in virtue



of which the longitudinal passage of an electric current through the bar is accompanied by an absorption of heat at one side of the bar and an evolution of heat at the opposite side, the two sides being kept at the same, or essentially the same, temperature. This is known as the *transverse Peltier effect*. (For a rectangular bar of Bi cut with its length at  $45^\circ$  to the axis of the crystal, distance between sides which became unequally heated = 1.55 mm, distance between other two sides = 2.64 mm, it was observed that  $\Delta t = 0.267^\circ\text{C}$  per ampere of longitudinal current, the bar being exposed to the air and at room temperature (16).) Conversely, a difference in temperature of the two sides gives rise to a longitudinal emf.

TABLE 1.—THERMO EMF AND THERMOELECTRIC POWER OF ELEMENTARY SUBSTANCES

$M E_R = at + \frac{1}{2}bt^2(10)^{-2} + \frac{1}{3}ct^3(10)^{-5} + d$ ; one junction at  $0^\circ\text{C}$ .

$M Q_R = d(M E_R)/dt = a + bt(10)^{-2} + ct^2(10)^{-5}$ .

$M P_R = T(M Q_R)$  = Peltier coefficient; difference in the Thomson coefficients is  $(\sigma_M - \sigma_R) = Td(M Q_R)/dt$ ;  $T$  = absolute temperature corresponding to temperature  $t$ . The tabulated coefficients apply for all values of  $t$  between  $t_1$  and  $t_2$ . For other notation, see introduction.

The numbers in the "Error" column indicate the possible departures ( $\pm$ ) of observed value of  $E$  from that calculated by means of the coefficients; unit is 1%, unless another is indicated.

The expression  $\left. \begin{matrix} -0.38 \\ -0.53 \end{matrix} \right\}$  indicates that the quantity varies from -0.38 to -0.53. Unit of  $E = 1\mu\text{V} = 10^{-6}$  volt;  $t_1, t_2$  = centigrade temperature,  $^\circ\text{C}$ .

M	R	$t_1$	$t_2$	a	b	c	Error	Lit.
Ag <sup>a</sup>	Pb	-200	+ 100	+ 2.947	+ 0.6782	- 0.186	1	(31)
Ag	Pb	0	+ 200	+ 3.3383	+ 0.847		1.5	(59)
Ag <sup>a</sup>	Pb	0	+ 100	+ 2.50	+ 1.15		1	(76)
Ag	Pt	0	+ 900	+ 3.04	+ 2.01		1.5	(65)
Al <sup>b</sup>	Pb	-200	+ 100	- 0.4717	+ 0.2718	- 2.386	1	(31)
Al <sup>b</sup>	Pb	0	+ 200	- 0.4960	+ 0.1734		1.5	(59)
Al <sup>c</sup>	Pb	0	+ 100	$\left. \begin{matrix} - 0.38 \\ - 0.53 \end{matrix} \right\}$	$\left. \begin{matrix} - 0.01 \\ + 0.21 \end{matrix} \right\}$	- 2.82		$\left. \begin{matrix} (76) \\ (17) \end{matrix} \right\}$
Al	Pt	0	+ 800	- 0.7982	- 0.9072	- 0.6717	1.5	(65)
Au	Pb	-260	0	+ 2.90	+ 0.68		1.5	(80)
Au	Pb	0	+ 200	+ 2.90	+ 0.934		1.5	(17, 59, 76)
Bi	Pb	-200	+ 100	- 81.845	+ 0.599	+ 162.5	1	(31)
Bi <sup>c</sup>	Pb	-200	+ 100	- 43.688	- 46.47	- 38.72	1	(31)
Bi <sup>c</sup>	Pb	0	+ 100	- 74.42	+ 3.2		1.5	(17)
Bi	Pt	0	+ 268	- 61.95	+ 4.502	+ 26.82	1.5	(65)
Bi	Pt	+300	+ 800	+ 15	$d = -17.900$		1.5	(65)
Bi <sup>c</sup>	Cu	+ 20	+ 100	- 55.0	- 3.12	(0.0°)*	1.0	(17)
Bi <sup>c</sup>	Cu	+ 20	+ 100	- 56.6	- 2.50	(5.5°)*	1.0	(17)
Bi <sup>c</sup>	Cu	+ 20	+ 100	- 59.0	- 10.00	(10.0°)*	5.0	(17)
Bi <sup>c</sup>	Cu	+ 20	+ 100	- 61.4	- 6.25	(17.7°)*	1.0	(17)
Bi <sup>c</sup>	Cu	+ 20	+ 100	- 61.1	- 8.75	(21.1°)*	1.0	(17)
C <sup>d</sup>	Pb	-200	+ 100	+ 11.056	+ 3.578	+ 5.379	1	(31)
C	Pt	0	+ 560	- 6.0072	+ 16.92	- 0.2274	2	(53)
Ca	Cu	0	+ 100	- 9.35	- 3.1		1	(60)
Ca <sup>d</sup>	Pb	0	+ 400	- 8.20	- 2.9			(77)
Cd	Pb	-200	+ 100	+ 3.059	+ 2.856	+ 9.00	1	(31)
Cd <sup>a</sup>	Pb	0	+ 200	+ 2.619	- 1.787		1.5	(59)
Cd <sup>b</sup>	Pb	0	+ 100	+ 2.85	+ 3.89		1	(76)
Cd	Pt	0	+ 320	+ 0.390	+ 0.38		0.5	(65)
Cd	Pt	+320	+ 700	+ 1.5	$d = -164$		0.5	(65)
Ce <sup>e</sup>	Cu	0	+ 200	+ 4.39	- 1.26		2	(44)
Co <sup>f</sup>	Cu	0	+ 280	- 20.51	- 5.4		2	(64)
Co	Cu	+340	+ 550	- 24.75	- 2.7		2	(64)
Co	Cu	+580	+ 900	- 62.6	+ 4.34	(+10 310)†		(64)
Co	Cu	0	+ 280	- 23.24	- 8.26		1.5	(66)
Co	Pt	0	+1 200	- 10.7	- 5.70	+ 7.50	2	(68)
Ca	Pt	-200	- 75	+ 4.66 <sup>p</sup>	+ 5.49 <sup>p</sup>			(11)
Ca	Pt	- 75	+ 5.8	+ 3.14	+ 3.453		(7)	(11)
Ca	Pt	+ 27.4	+ 300	+ 15.73 <sup>p</sup>	- 4.93 <sup>p</sup>			(11)
Ca	Pb	-183	0	+ 0.66	- 0.10			(19)
Ca	Pb	+ 28	+ 100	+ 7.735	- 3.34			(19)

TABLE 1—(Continued)

M	R	$t_1$	$t_2$	a	b	c	Error	Lit.
Cu <sup>d</sup>	Pb	-270	+ 200	+ 2.705	+ 0.7866	+ 1.773	1	(31, 59, 62, 80)
Cu <sup>a</sup>	Pb	0	+ 100	+ 2.76	+ 1.22		1	(76)
Cu	Pt	0	+ 900	+ 3.130	+ 2.460		1	(65)
Fe	Pb	-260	- 200	- 51.34	- 20.4	(-2 912)†	0.25	(80)
Fe <sup>m</sup>	Pb	-230	+ 100	+ 16.65	- 2.966	- 26.75	1	(17, 31, 80)
Fe	Pt	0	+1 000	r. Table 2				
Fe <sup>a</sup>	Cu	0	+ 700	+ 13.7	- 7.80	+ 6.60	1	(18)
Ge	Pt	-200	+ 125	+ 302.5	+ 72.5		1	(11)
Ge	Pt	+135	+ 275	- 219†	+ 766	-2 391		
Ge	Pt	+275	+ 500	+1 422‡	- 702	+ 762		
Ge	Pt	+500	+ 700	- 362	+ 31.2	(+204.9)§		(11)
Hg	Pb	0	+ 200	- 8.8103	- 3.333		1.5	(59)
In	Pb	0	+ 100	+ 2.40	+ 0.190			(33.1)
Ir	Pt	+250	+1 500	- 7.282	- 1.108	(+248)§		(45)
Ir <sup>a</sup>	Pb	- 80	+ 100	+ 2.44	- 0.28		1	(19)
K	Pb	-183	0	- 11.33	- 3.76		1	(19)
K	Pt	-200	- 113	- 4.64 <sup>p</sup>	+ 2.41 <sup>p</sup>			(11)
K	Pt	-113	+ 53	- 8.09	- 0.59		(7)	(11)
K	Pt	+ 62.5	+ 300	- 5.41 <sup>p</sup>	- 0.017 <sup>p</sup>			(11)
Li	Pt	-200	+ 50	+ 14.37	+ 8.76			(11)
Li	Pt	+ 50	+ 168	+ 16.71 <sup>p</sup>	+ 4.08 <sup>p</sup>		(7)	(11)
Li	Pt	+183	+ 300	+ 20.57 <sup>p</sup>	+ 5.39 <sup>p</sup>			(11)
Mg	Pb	-200	+ 100	- 0.2010	+ 0.2572	- 1.677	1	(31)
Mg <sup>a</sup>	Pb	0	+ 200	- 0.120	+ 0.193		1.5	(59)
Mg	Pt	0	+ 700	+ 5.0	+ 1.444		1	(68)
Mo	W	0	+1 050	+ 4.61	+ 0.872		4	(60)
Mo	W	+950	+2 350	+ 24.5 <sup>e</sup>	- 188.6 <sub>4</sub>		5.0	(57.1)
Mo	Pb	0	+ 100	+ 5.892	+ 4.334	- 7.50	1.5	(17)
Mo	Pt	0	+1 200	+ 13.0	+ 2.96		2.5	(68)
Na	Pt	-200	+ 8.1	- 0.882	+ 4.104			(11)
Na	Pt	+ 8.1	+ 84.7	- 0.482 <sup>p</sup>	- 0.833 <sup>p</sup>		(7)	(11)
Na	Pt	+ 97	+ 300	+ 3.222 <sup>p</sup>	- 2.094 <sup>p</sup>			(11)
Na	Pb	-183	0	- 4.16	- 1.44			(19)
Ni <sup>a</sup>	Pb	-200	+ 100	- 16.325	- 5.346	+ 5.703	1	(31)
Ni <sup>a</sup>	Pb	0	+ 200	- 19.067	- 3.022		1.5	(59)
Ni	Pb	-260	0	- 17.633	- 5.016	+ 1.137	0.02	(80)
Ni	Pt	0	+ 313	- 2.891	+ 0.622		0.5	(65)
Ni	Pt	+313	+ 900	+ 0.484**	- 0.366	+ 0.1616	0.5	(68)
Ni	Pt	0	+1 200	- 17.12	+ 2.46	- 2.193	2	(68)
Pd	Pb	-200	+ 100	- 7.409	- 3.922	+ 12.65	1	(31)
Pt <sup>a</sup>	Pb	-200	+ 300	- 3.038	- 3.248	+ 8.409	1.5	(17, 31, 59)
Pt <sup>a</sup>	Pb	0	+ 100	- 1.788	- 3.460	+ 12.6	1	(17)
Pt	Pb	-260	0	- 6.677	+ 0.1528		0.5	(80)
Rb	Pt	-200	- 25	- 3.537 <sup>p</sup>	+ 1.851 <sup>p</sup>			(11)
Rb	Pt	- 25	+ 23.2	- 4.332	- 1.328		(7)	(11)
Rb	Pt	+ 37.2	+ 300	+ 2.141 <sup>p</sup>	- 5.76 <sup>p</sup>			(11)
Rb	Pb	-183	0	- 8.26	- 3.02			(19)
Rb	Pb	+ 38	+ 100	- 0.28 <sup>p</sup>	- 6.00 <sup>p</sup>			(19)
Rh <sup>a</sup>	Pb	- 78	+ 100	+ 2.17	+ 0.05			(19)
Rh	Pt	0	+1 300	+ 6.27	+ 1.612	+ 0.1797	2.5	(45)
Sb	Pt	0	+ 630	+ 46.24	+ 6.362	- 14.33	2	(65)
Sb	Pt	+650	+ 711		+2 100 <sup>p</sup>			(65)
Sb <sup>b</sup>	Pb	0	+ 100	+ 35.58	+ 14.50		1.5	(41, 76)
Se <sup>v</sup>	Pb	+ 10	+ 100	b = +99 030 <sup>p</sup> to 114 000 <sup>p</sup>				(46.1)
Si	Pb	-200	+ 350	- 408.2	- 46.96	+351.0	3	(79)
Sn	Pb	-260	0	- 0.11	+ 0.264		3 mov.	(80)
Sn	Pb	-200	+ 100	+ 0.0684	+ 0.0038	- 0.266	1%	(31)
Sn	Pb	0	+ 100	- 0.111	+ 0.040		1	(76)
Sn	Pb	0	+ 100	+ 0.230	- 0.134		1	(17)
Sn	Pb	0	+ 200	- 0.168	+ 0.187		1.5	(59)
Sn	Pt	0	+ 415	+ 2.870	+ 2.3		0.5	(65)
Sn	Pt	+415	+ 600	+ 13.0	$d = -2 200$		0.5	(65)
Ta	Cu	-200	+ 100	- 3.358	- 1.343		3 mov.	(27)
Ta <sup>a</sup>	Pt	0	+ 400	+ 2.20	+ 2.46		2%	(64)
Ta	Pt	0	+1 200	+ 2.0	+ 2.64		3	(66)
Te	Cu	Qu < 352, Q <sub>18</sub> = +434††						(41)
		An < 352, Q <sub>18</sub> = +229††						(41)
		Ht > 352, Q <sub>18</sub> = +160††						(41)
Te <sup>c</sup>	Cu	+ 20	+ 100	+ 191.2	- 275.0	(0.0°)§§	1.0	(17)
Te <sup>c</sup>	Cu	+ 20	+ 100	+ 148.7	- 168.9	(7.5°)§§	1.0	(17)
Te <sup>c</sup>	Cu	+ 20	+ 100	+ 277.2	- 361.2	(12.5°)§§	1.0	(17)
Tl <sup>a</sup>	Pb	0	+ 100	+ 2.14	- 0.77		1	(76)
Tl	Pb	0	+ 100	+ 1.659	- 0.268	- 1.68	1	(17)
Tl	Pt	0	+ 310	+ 5.18	+ 1.34		1	(65)
Tl	Pt	+310	+ 404	- 156††	+ 70.66	- 111.9	1	(65)
W	Pb	0	+ 100	+ 1.594	+ 3.41		1	(17)



TABLE 1.—(Continued)

M	R	t <sub>1</sub>	t <sub>2</sub>	a	b	c	Error	Lit.
W	Cu	-200	+ 300	- 1.080	+ 2.334	+ 2.375	5 mev.	(27)
W	Cu	0	+ 630	- 1.12	+ 1.695		2%	(64)
W	Pt	0	+1 200	+ 9.4	+ 3.68		2	(68)
W	Ta	+950	+2 430	+ 5.21	+ 590		2.0	(57.1)
Zn	Pb	-260	0	+ 3.096	+ 3.191	+ 10.99	1	(50)
Zn <sup>w</sup>	Cu	+ 20	+ 100	- 0.919	+ 0.28	(35.0°)	1.0	(17)
Zn <sup>w</sup>	Cu	+ 20	+ 100	- 1.012	+ 0.93	(46.5°)	1.0	(17)
Zn <sup>w</sup>	Cu	+ 20	+ 100	- 0.725	+ 0.75	(48.0°)	1.0	(17)
Zn <sup>w</sup>	Cu	+ 20	+ 100	- 0.400	+ 0.59	(57.0°)	1.0	(17)
Zn <sup>w</sup>	Cu	+ 20	+ 100	- 0.200	+ 0.75	(60.0°)	1.0	(17)
Zn <sup>w</sup>	Cu	+ 20	+ 100	+ 0.154	+ 0.82	(80.0°)	1.0	(17)
Zn <sup>w</sup>	Cu	+ 20	+ 100	+ 0.135	+ 0.97	(83.0°)	1.0	(17)
Zn <sup>w</sup>	Cu	+ 20	+ 100	+ 0.232	+ 0.97	(86.5°)	1.0	(17)
Zn <sup>d</sup>	Pb	-200	+ 100	+ 2.607	+ 1.074	+ 1.39	1	(31)
Zn	Pb	0	+ 100	+ 3.047	- 0.99		1.5	(17)
Zn <sup>c</sup>	Pb	0	+ 250	+ 3.181	- 0.113		1.5	(59)
Zn	Pt	0	+ 450	+ 5.74	+ 3.30		1.5	(31, 59, 65)
Zn	Pt	+450	+ 700	- 17	d = +1 820		1.5	(66)

\* Angle between basal cleavage plane and direction of current.

† Value of d; c = 0.

‡ d = 26 716.

§ d = -87.46.

|| Value of d; c = 0.

||| d = -12 400.

\*\*\* d = -600.

†† Qu < 352, [An < 352] = quenched [annealed] from below 352°C; Ht > 352 = after heating above 352°C; Q<sub>15</sub> = Q at 15°C.

‡‡ d = +12 420

§§ Angle between crystal axis and direction of current.

||| d = 1 320.

\* Annealed. \* 99% pure. \* Commercial. \* 99.57% pure. \* Electrolytic. / Filament of incandescent lamp. \* Cold-drawn and hammered. \* Heraeus made. \* 99.8% Co, 0.2% Si, traces Fe. / Electrolytic, cold-drawn, annealed in hydrogen. \* Pure "Swedish," hard-drawn, used for gold refining. \* Very soft, annealed transformer Fe. \* Deposited from nickel carbonyl. \* 97.7% Co, 1.2% Fe, remainder cerium oxide and cerium carbide. \* Applies to equation for Q only. \* Baker's platinum. \* Used in cast form, solid rods soldered end to end. \* Slight traces of carbon. \* Traces of Fe. \* 97.9% Pt, 1.5% Pb, traces of Cu and Au. \* Se in darkness; in light sufficient to increase its conductivity 100%, Q is decreased by 4%. \* Single crystal.

TABLE 2.—THERMOELECTRIC POWER (F<sub>0</sub>Q<sub>Pt</sub>) OF COUPLES OF PURE IRON AND PLATINUM (22)

The pure iron contained 99.968 Fe, 0.009 C, 0.009 S, 0.001 P, 0.006 Si, 0.001 Mn and 0.006 Cu; the platinum was purest Heraeus Pt. For the Fe, the A<sub>1</sub> transformation point near 700°C, due to C, is absent; A<sub>2</sub> is at 768°C, A<sub>3</sub> and A<sub>4</sub> are at 900 and 910°C, respectively. Unit of Q = 1 μV/°C = 10<sup>-6</sup> volt/°C; t = centigrade temperature, °C.

t	F <sub>0</sub> Q <sub>Pt</sub>	t	F <sub>0</sub> Q <sub>Pt</sub>	t	F <sub>0</sub> Q <sub>Pt</sub>
0	+19.5	775	+18.1	Temp. rising	
100	+18.1	800	+18.4	1000	+12.6
200	+15.4	880	+19.4	Temp. falling	
300	+11.7	Temp. rising		930	+11.1
400	+ 9.5	900	+19.7	920	+10.9
500	+ 9.1	910	+19.4	910	+10.8
600	+10.8	920	+16.6	900	+17.5
700	+14.3	930	+11.4		

TABLE 3.—THERMOELECTRIC POWER (Q) AND THERMO EMF (E) OF ALLOYS (MAINLY BINARY ALLOYS)

For list of commercial alloys and miscellaneous mixtures, see end of table.  $Q = a + bt(10)^{-2} + ct^2(10)^{-5}$ ;  $E = at + \frac{1}{2}bt^2(10)^{-2} + \frac{1}{3}ct^3(10)^{-5} + d$ , one junction at 0°C; E can not be obtained from Q unless the value of d is known, but d is generally zero if no transformation point occurs between 0°C and t, °C. "t<sub>1</sub> t<sub>2</sub>" denotes

that the coefficients apply if t lies between t<sub>1</sub> and t<sub>2</sub>. Unit of Q = 1 μV/°C = 10<sup>-6</sup> volt/°C; t = centigrade temperature, °C.

Ag-Al; 0° t 100°; Q<sub>Pb</sub> (18)

Vol. % Ag*	Annealed		Quenched	
	a	b	a	b
0.00	-0.07	-0.02	-0.04	-0.06
4.98	+0.67	-0.22	+0.43	-0.35
10.1	+0.74	-0.16	+0.70	-0.19
20.1	+0.93	+0.32	+1.05	+0.13
30.3	+1.24	+0.63	+1.39	+0.44
39.7	+1.58	+0.68	+1.84	+0.53
50.6	+2.24	+0.81	+2.75	+0.95
56.1	+2.90	+1.15	+3.25	+1.22
58.0	+3.01	+1.20	+3.56	+1.24
60.9†	+3.67	+2.13	+4.03	+1.54
63.5	+2.75	+0.96	+2.88	+0.81
67.4	+1.74	+0.56	+1.80	+0.58
69.8	+1.37	+0.34	+1.53	+0.22
73.2‡	+0.95	+0.37	+1.36	+0.25
75.4	+1.08	+0.40	+1.23	+0.29
80.0	+2.23	+0.55	+2.15	+0.64
90.3	+1.83	+0.35	+1.76	+0.48
95.1	+1.51	+0.47	+1.46	+0.40
100.0	+2.51	+0.76	+2.44	+0.72

\* Electrolytic Ag. † Ag<sub>2</sub>Al<sub>3</sub>. ‡ Ag<sub>2</sub>Al.Ag<sub>2</sub>Al<sub>3</sub>-AlCu<sub>3</sub>; 0° t 100°; Q<sub>Pb</sub> (18)

Vol. % Ag <sub>2</sub> Al <sub>3</sub>	Annealed		Quenched	
	a	b	a	b
0	-1.36	+0.37	+1.48	+0.77
11.6	-4.18	-0.91	-3.79	+0.11
31.3	+3.71	+2.39	-2.93	+0.31
50.2	+6.94	+1.75	+9.56	+2.47
69.1	+3.99	+1.30	+6.27	+1.82
92.4	+2.78	+1.18	+3.15	+0.97
100.0	+3.67	+2.13	+4.03	+1.54

Ag-Au; 0° t 100°; Q<sub>Cu</sub> (69)

Wt. % Au	a	b	Wt. % Au	a	b
0	+0.20	0.00	60	-2.13	-1.34
5	-1.34	-0.53	80	-2.16	-0.94
20	-2.70	-0.40	95	-0.84	-0.32
40	-2.40	-1.20	100	-0.00	-0.00

Ag-Cd; 0° t 100°; Q<sub>Cu</sub> (71)

At. % Cd	a	b	At. % Cd	a	b
0.0	-0.31	+0.04	11.9	-1.41	-0.30
4.0	-1.32	-0.23	16.3	-1.42	-0.38
8.8	-1.42	-0.30	25.7	-1.23	-0.29

Ag-Hg; see Hg

Ag-Pd; 0° t 900°; Q<sub>Pt</sub> (39)

Wt. % Ag	a	b	c
0	- 2.61	-0.444	-1.296
10	- 6.89	-2.778	+0.185
20	-11.44	-5.444	+2.037
30	-16.56	-7.444	+3.518
40*	-26.78	-6.667	+3.704
50	-20.333	-4.333	+1.667
60	-10.55	-1.889	-0.926
70	- 4.72	-0.333	-1.481
80	- 1.17	-0.278	-0.278
90	+ 0.22	+2.000	-0.741
100	+ 5.67	+2.667	-0.000

\* Ag<sub>2</sub>Pd<sub>3</sub>.



Ag-Pt; 0° t 900°;  $Q_{Pt}$  (39)

Wt. % Pt	a	b	Wt. % Pt	a	b
10	+0.50	+1.00	30	-3.375	-0.938
25	-1.50	-0.624	33	-4.25	-1.00

Ag-Sb;  $t = 18^\circ$ ;  $Q_{Cu}$  (41); error =  $\pm 4.5\%$ 

Wt. % Sb	$Q_{Cu}$	Wt. % Sb	$Q_{Cu}$	Wt. % Sb	$Q_{Cu}$
10	-1.7	29	-6.8	70	+14.33
15	-1.2	30	-5.55	80	+17.63
20	-0.91	31	-4.0	90	+20.5
25	-2.32	35	+1.32	95	+22.5
27	-2.9	40	+2.98	100	+32.0
27.07	-4.8	50	+8.15		
28*	-7.65	60	+12.12		

\* Ag<sub>3</sub>Sb.Ag-Sn; 0° t 100°;  $Q_{Cu}$  (10); for 4 Wt. % Sn, a = -8.21, b = +3.39Ag-Tl; 0° t 100°;  $Q_{Cu}$  (10)

Wt. % Tl	a	b	Wt. % Tl	a	b
2.73	+2.95	-0.81	4.76	+12.24	-0.108

Al-Bi; 0° t 100°;  $Q_{Pb}$  (18)

Vol. % Bi*	Annealed		Quenched	
	a	b	a	b
0	-0.07	-0.02	-0.04	-0.06
1.89	-0.36	-0.01	-0.25	-0.05
4.83	-0.85	-0.12	-0.46	-0.01
10.0	-0.92	-0.20	-0.54	-0.02
30.0	-9.27	-2.05	-9.06	-2.09
50.0	-21.9	-2.14	-22.5	-2.14
70.0	-32.6	-3.60	-36.8	-3.36
90.0	-45.7	-0.12	-55.1	-3.02
94.6	-52.7	-1.24	-58.6	-3.48
97.9	-57.8	-1.46	-65.6	-2.01
100.0*	-58.7	-3.26	-55.7	-0.34

\* Electrolytic.

Al-Cu; 0° t 100°;  $Q_{Pb}$  (18)

Vol. % Cu	Annealed		Quenched	
	a	b	a	b
0	-0.07	-0.02	-0.04	-0.06
1.18	+0.29	+0.23	+0.44	+0.07
2.78	+0.37	+0.58	+0.62	+0.22
6.41	+0.27	+0.45	+0.50	+0.15
10.6	+0.09	+0.27	+0.34	+0.06
16.3	+0.03	+0.20	+0.12	+0.03
22.1	-0.24	-0.24	+0.06	-0.47
24.1	-0.20	-0.40	-0.05	-0.41
26.2*	-0.28	-0.42	-0.11	-0.41
31.6	+1.44	+0.61	+1.32	+0.48
37.9	+3.65	+1.38	+3.30	+1.26
41.7†	+3.80	+1.55	+3.96	+1.46
47.3	+3.48	+1.32	+3.30	+1.14
50.1	+2.72	+1.15	+2.98	+1.00
51.7†	+2.81	+1.20	+2.76	+0.96
52.6	+6.64	+1.34	+5.83	+1.60
54.4	+11.80	+2.65	+11.25	+2.34
58.8	+6.07	+1.00	+6.10	+1.58
64.7	-2.32	+0.23	-1.22	+0.50
68.3‡	-1.36	+0.37	+1.48	+0.77
74.3	+1.78	+0.74	+2.33	+0.79
80.3	+2.06	+0.71	+2.27	+0.73
86.0	+2.15	+0.68	+2.17	+0.69
94.0	+2.24	+0.66	+2.24	+0.66
100.0	+2.88	+0.98	+2.88	+0.98

\* Al<sub>2</sub>Cu. † AlCu. ‡ Al<sub>3</sub>Cu<sub>2</sub>. § AlCu<sub>2</sub>.Al-Cu; 0° t 820°;  $Q_{Cu}$  (64)

Wt. % Cu*	a	b	Wt. % Cu*	a	b
6.0	-2.21	-0.680	94.0	-1.78	-0.040
90.0	-1.21	-0.104	95.0	-2.53	-3.20
92.5	-1.59	-0.090	97.0	-2.31	-3.00

\* Electrolytic.

Al-Fe; 0° t 100°;  $Q_{Pb}$  (18)

Vol. % Fe*	Annealed		Quenched	
	a	b	a	b
0	-0.07	-0.02	-0.04	-0.06
4.85	-0.65	-0.53	-1.07	-0.39
9.90	-1.46	-1.37	-2.04	-1.26
14.9	-2.13	-2.03	-2.45	-1.90
19.1	-2.65	-3.14	-2.85	-2.86
25.7			-4.17	-1.98

\* Swedish Fe; 0.08 % C.

Al-Mg; 0° t 100°;  $Q_{Pb}$  (18)

Vol. % Mg*	Annealed		Quenched	
	a	b	a	b
0.0	-0.07	-0.02	-0.04	-0.06
5.68	+0.84	-0.39	+1.04	-0.59
10.28	+1.12	-0.58	+1.11	-0.58
20.7	+0.85	-0.55	+0.91	-0.58
25.4	+0.72	-0.70	+0.75	-0.56
30.3	+0.21	-0.42	+0.25	-0.37
39.5	-0.40	-0.40	-0.82	-0.28
41.2	-0.42	-0.55	-0.76	-0.43
46.0	-0.56	-0.60	-1.38	-0.37
51.7	-0.95	-0.82	-2.49	-0.56
58.5†	-4.19	-1.08	-4.56	-0.88
62.8	+1.68	-1.53	+1.57	-1.50
64.3	+3.51	-1.18	+3.48	-0.99
65.3	+3.53	+0.86	+3.43	+0.60
67.8†	+1.22	+0.30	+1.01	+0.36
70.1	-0.05	+0.10	-0.13	+0.23
73.9	-0.33	+0.09	-0.99	-0.02
80.7	-0.78	-0.05	-1.52	-0.16
89.9	-1.64	-0.18	-1.86	-0.22
95.3	-1.64	-0.18	-1.46	-0.55
100.0	+0.18	-1.02	+0.24	-0.83

\* 99.2 % Mg, 0.3 % Fe, 0.5 % Si by Wt. † AlMg. ‡ Al<sub>2</sub>Mg.Al\*-Mg; † 0° t 420°;  $Q_{Cu}$  (60)

Wt. % Al*	a	b	c
0	-2.656	-0.7082	
10†	-6.423	+1.196	-4.961
87.5†	-2.057	-0.7871	
90†	-1.780	-0.980	
90†§	-2.132	-0.836	
100	-4.495	+2.408	-12.877

\* 99.67 % Al, 0.16 % Si, 0.15 % Fe, 0.02 % Cu. † Pure Mg. ‡ Cold-drawn. § Contains 8 % Mg and 2 % Ni. || Heated red-hot and cooled in air.

Al-Mn; 0° t 100°;  $Q_{Pb}$  (18)

Vol. % Mn*	Annealed		Quenched	
	a	b	a	b
0.0	-0.07	-0.02	-0.04	-0.06
2.40	-5.04	-0.46	-5.17	-0.80
5.01	-4.93	-0.91	-4.68	-0.97
8.99	-4.81	-0.71	-4.62	-1.12
15.1	-4.53	-0.58	-4.47	-1.08
19.8†	-0.56	-1.48	-1.62	-1.66
24.1	+27.3	+2.59	+3.44	-0.21

\* 96.8 % Mn, 1.8 % Al, 0.9 % Si, 0.5 % Fe, by Wt. In computing Vol. % of alloy, an allowance was made for the Al in the Mn. † Al<sub>2</sub>Mn.



Al-Ni; 0° t 100°;  $Q_{Pb}$  (18)

Vol. % Ni*	Annealed		Quenched	
	a	b	a	b
3.81	-0.56	-0.07	-0.50	-0.10
8.12	-0.75	-0.10	-0.68	-0.27
11.7	-1.30	-0.15	-1.21	-0.32
18.4†	-1.35	-0.22	-0.83	-0.73
19.8	-0.91	-0.36	-0.80	-0.76
60.7	-0.93	-0.31	-4.57	-3.39
66.4	+6.02	+0.39	+6.07	-0.05
70.3	+10.4	-0.24	+10.3	-0.45
79.3	-5.30	-1.39	-4.93	-3.50
90.0	-17.3	-4.94	-14.9	-7.98
94.9	-16.8	-5.62	-16.9	-6.96
100.0	-16.2	-5.95	-16.2	-5.95

\* No trace of Fe. † Al<sub>3</sub>Ni.Al-Ni; 0° t 1200°;  $Q_{Pt}$  (68)

Wt. % Al	a	b
5	-5.671	-0.6218

Al-Pb; 0° t 200°;  $Q_{Cu}$  (64)

Wt. % Al	a	b	Wt. % Al	a	b
0	-2.58	+0.02	96.0	-1.25	-1.00
92.0	-1.19	+0.07	100.0	-1.62	-0.59
94.0	-1.41	+0.06			

Al-Sb; 0° t 400°;  $Q_{Cu}$  (64)

Wt. % Sb	a	b	c
0.0	-1.030	-2.243	+8.665
60.0	-0.816	-0.598	+2.607
62.0	-0.233	-0.726	+2.492
65.0	-0.781	-0.968	+3.626
70.0	-0.306	-1.083	+3.715
100.0	-34.50	-4.941	+48.38

Al-Sn; 0° t 100°;  $Q_{Pb}$  (18)

Vol. % Sn	Annealed		Quenched	
	a	b	a	b
5.03	-0.40	+0.25	-0.34	+0.46
10.1	-0.41	+0.23	-0.47	+0.48
19.9	-0.51	+0.38	-0.54	+0.54
29.2	-0.54	+0.53	-0.60	+0.66
40.2	-0.54	+0.53	-0.51	+0.64
49.8	-0.54	+0.56	-0.50	+0.64
51.4	-0.51	+0.48	-0.45	+0.55
59.4	-0.52	+0.54	-0.43	+0.61
62.0	-0.36	+0.45	-0.45	+0.55
69.8	-0.47	+0.48	-0.38	+0.61
80.0	-0.30	+0.53	-0.28	+0.58
90.5	-0.17	+0.48	-0.18	+0.53
95.0	-0.14	+0.42	-0.14	+0.42
100.0	-0.14	+0.42	-0.14	+0.42

\* Al is soluble in Sn in all proportions.

Al-Zn; 0° t 100°;  $Q_{Pb}$  (18)

Vol. % Zn	Annealed		Quenched	
	a	b	a	b
4.60	+0.41	+0.07	+0.55	+0.29
9.50	+0.53	+0.32	+0.78	+0.40
19.3	+0.71	+0.44	+0.88	+0.47
29.0	+0.98	+0.52	+1.01	+0.58
39.3	+1.19	+0.66	+1.17	+0.69
49.6	+1.40	+1.00	+1.43	+1.04
60.0	+1.56	+1.05	+1.64	+1.13

## Al-Zn.—(Continued)

Vol. % Zn	Annealed		Quenched	
	a	b	a	b
68.7	+1.68	+1.20	+1.83	+1.30
78.4	+1.83	+1.26	+1.85	+1.31
89.0	+2.02	+1.54	+2.13	+1.50
95.0	+2.09	+1.69	+2.60	+1.56
100.0	+1.84	+1.59	+1.62	+1.36

\* 99.7 % Al, 0.1 % Fe, 0.2 % Si, by Wt.

† Al is soluble in Zn in all proportions.

Au-Cd; 0° t 100°;  $Q_{Cu}$  (71)

At. % Cd	a	b	At. % Cd	a	b
0.0	-0.17	-0.03	8.7	-1.81	-0.50
5.4	-1.52	-0.19	17.2	-2.39	-0.48

Au-Cu; 0° t 150°;  $Q_{Cu}$  (69)

Wt. % Cu	a	b	Wt. % Cu	a	b
10.0	-0.40	-0.80	60.0	-0.83	-0.80
20.0	-0.84	-0.82	80.0	-0.59	-0.68
40.0	-0.88	-0.78	95.0	+0.25	-0.70

Au-Pd; 0° t 1000°;  $Q_{Pt}$  (39)

Wt. % Au	a	b	c
10.0	-7.944	-1.111	-0.185
20.0	-11.722	-1.556	+0.185
30.0	-12.722	-3.111	+1.296
40.0	-14.333	-5.222	+2.778
50.0	-21.777	-5.556	+3.704
60.0*	-26.444	-6.778	+5.370
70.0	-26.000	-0.444	-1.111
80.0	-4.111	-1.000	-0.185
90.0	-1.000	+1.000	-0.556
100.0	+6.777	+2.556	-0.926

\* AuPd.

Au-Pt;  $Q_{Pt}$  is negative and on repeated or continued heating increases continually in absolute value, not becoming constant even after 2 hr at 900°C; its absolute value increases with the Pt content (39).

Au-Sb;  $t = 18^\circ$ ;  $Q_{Cu}$  (41)

Wt. % Sb.....	50	55*	60
$Q_{Cu}$ (18°).....	-1.07	-17.0	-0.31

\* AuSb<sub>2</sub>.Au-Zn; 0° t 100°;  $Q_{Cu}$  (71)

At. % Zn	a	b	At. % Zn	a	b
0.0	-0.17	-0.03	10.1	-2.25	-0.53
4.9	-1.85	-0.01	18.3	+0.33	+0.58

Bi-Cd; 0° t 125°;  $Q_{Cu}$  (69)

Wt. % Cd	a	b	Wt. % Cd	a	b
0.0	-105.50	+54.00	40.0	-31.04	+15.08
5.0	-77.50	+39.60	70.0	-12.34	+5.08
10.0	-68.27	+37.34	90.0	-5.47	+2.14
25.0	-47.13	+25.06	100.0	+1.56	+0.48

## Bi-Hg; see Hg

Bi-Pb;  $t_1$  t  $t_2$ ;  $E_{Cu}$  (28)

Wt. % Pb	$t_1$	$t_2$	a	b	d
10.0	0	200	-8.25	-15.50	0
	241	450	-17.05	+3.30	-2000
20.0	0	110	+2.50	0.00	0
	110	200	-11.50	-17.0	0
	200	450	0	-1.50	-1000
30.0	0	120	+10.00	0.00	0
	126	450	-2.083	-0.834	+1250



## Bi-Pb.—(Continued)

Wt. % Pb	$t_1$	$t_2$	a	b	d
40.0	0	110	+ 2.50	0.00	0
	110	450	- 6.365	+ 0.230	+1000
50.0	0	450	- 1.975	- 0.825	0
60.0	0	450	- 2.750	- 0.750	0

Bi-Pb;  $0^\circ$  to  $150^\circ$ ;  $Q_{Pb}$  (6)

Vol. % Bi	a	b	Vol. % Bi	a	b
5.5	-0.0	+0.50	91.5	+ 2.00	-1.00
12.0	-0.0	+0.50	94.5	+ 0.50	-0.50
22.5	-0.30	+1.00	100.0	-30.00	-5.00
82.5	+2.50	-1.00			

Bi-Sb;  $t = 18^\circ$ ;  $Q_{Cu}$  (41)

Wt. % Sb	$Q_{Cu}$	Wt. % Sb	$Q_{Cu}$	Wt. % Sb	$Q_{Cu}$
2.0	-71.5	30.0	-42.0	70.0	+ 7.55
5.0	-74.7	40.0	-19.0	80.0	+15.5
10.0	-77.7	50.0	-11.0	85.0	+18.0
15.0	-63.7	55.0	- 3.8	90.0	+23.5
20.0	-53.3	60.0	- 1.95	95.0	+26.7

Bi-Sb;  $Q_{Cu}$  (38)

$t =$	-190°C	-77°C	0°C	+100°C
Wt. % Sb	$Q_{Cu}$			
0	- 30	- 75	-72	-64
9	-153	-103	-87	-77
11	-156	- 98	-84	-74
13	-130	- 95	-83	-73
20	-110	- 83	-71	-60
50	- 15	- 21	-21	-14
70	+ 3.4	+ 6.3	+ 8.6	+13
100	+ 12	+ 29	+36	+45

Bi-Sn;  $0^\circ$  to  $100^\circ$ ;  $Q_{Cu}$  (24)

Wt. % Sn	a	b	Wt. % Sn	a	b
0.0	-40.20	-50.0	3.72	+29.4	-24.0
1.0	+ 6.77	-33.5	6.36	+39.4	-26.0
2.0	+26.0	-46.5	9.93	$Q = +38.0$ if $t = 20.7^\circ$	

Bi-Sn;  $t_1$  to  $t_2$ ;  $E_{Cu}$  (28)

Wt. % Sn	$t_1 = 0, t_2 = 130$	$t_1 = 150, t_2 = 450$	
	a	a	d
10	+32.4*	-4†	+5300†
20	+27.6	-2.39†	+4300†
30	+18.0	-3.38	+2790
40	+13.35	-3.79§	+2190§
50	+10.0	-3.38	+1770
60	+ 3.75	-0.0042	+ 420
70	+ 1.80	-0.00518	+ 270

\*  $t_2 = 125$ . †  $t_1 = 200$ . ‡  $t_1 = 210$ . §  $t_1 = 130$ .Bi-Sn;  $t = 30.7^\circ$ ;  $Q_{Pb}$  (48)

Wt. % Bi	$Q_{Pb}$	Wt. % Bi	$Q_{Pb}$	Wt. % Bi	$Q_{Pb}$
50.0	+ 8.75	90.0	+45.09	99.25	+12.96
60.0	+12.55	95.0	+45.62	99.62	+ 0.41
70.0	+20.14	97.5	+41.34	100.0	-64.66
80.0	+28.26	98.75	+33.48		

Bi-Te;  $t = 18^\circ$ ;  $Q_{Cu}$  (41)

Wt. % Bi	$Q_{Cu}$	Wt. % Bi	$Q_{Cu}$	Wt. % Bi	$Q_{Cu}$
2.0	+127.0	35.0	- 77.3	53.0	+62.0
5.0	+ 71.1	40.0	- 90.1	55.0	+27.7
10.0	+ 58.4	42.0	- 99.0	60.0	-18.3
13.9	+ 33.0	45.0	- 89.0	70.0	-21.8
15.0	+ 20.0	49.0	- 36.0	80.0	-16.2
20.0	- 9.83	50.0	+ 52.0	85.0	-11.0
25.0	- 37.0	52.0	+ 93.3	95.0	- 3.5
30.0	- 54.0	52.14*	+121.8	100.0	-57.4

\* Bi<sub>2</sub>Te<sub>3</sub>.Cd-Hg;  $0^\circ$  to  $100^\circ$ ;  $Q_{Cu}$  (10); see also Hg-Metal

Wt. % Hg	a	b	Wt. % Hg	a	b
5.14	-4.33	+5.16	10.0	-3.62	+5.65

Cd-Pb;  $0^\circ$  to  $100^\circ$ ;  $Q_{Pb}$  (6)

Vol. % Cd	8.0	15.0	73.8	85.0
a	+1.05	+1.75	+2.10	+2.60
b	+2.9	+3.4	+4.1	+3.9

Cd-Sb;  $0^\circ$  to  $150^\circ$ ;  $Q_{Pb}$  (6)

Vol. % Sb	a	b	Vol. % Sb	a	b
6.6	+ 5.0	+ 4.0	58.5	+235.0	+48.0
25.8	+20.0	+13.0	66.5	+420.0	+63.0
41.0	+70.0	+19.0	72.0	+235.0	+46.0

Cd-Sb;  $Q_{Cu}$ \*

Wt. % Sb	18°C (41)	50°C (8)	Wt. % Sb	18°C (41)	50°C (8)
	$Q_{Cu}$			$Q_{Cu}$	
0	+0.38		51.7	+305.0	
33.3		+ 4.48	66.7		+87.20
50.0		+134.2	100	+ 32.0	

\* For 50 atom %,  $Q_{Cu}$  varies rapidly with composition and is much affected by unhomogeneous structure; mean value between 18 and 55°C may amount to +543 (35, 35.1).Cd-Sn;  $0^\circ$  to  $150^\circ$ ;  $Q_{Cu}$  (69)

Wt. % Cd	a	b	Wt. % Cd	a	b
0.0	-2.73	-1.34	70.0	-0.30	+1.60
10.0	-2.60	-0.34	90.0	-0.40	+3.20
30.0	-1.66	-0.28	100.0	-0.06	+3.72
50.0	-1.33	+1.06			

Cd-Zn;  $0^\circ$  to  $150^\circ$ ;  $Q_{Cu}$  (69)

Wt. % Cd	a	b	Wt. % Cd	a	b
0.0	+0.20	0.00	70.0	-0.56	+4.04
10.0	-0.267	+0.53	90.0	-0.63	+4.22
30.0	-0.99	+2.58	100.0	-0.06	+3.72
50.0	-0.54	+2.68			

Co-Cu;  $t = 50^\circ$ ;  $Q_{Cu}$  (66)

Wt. % Co	$Q_{Cu}$	Wt. % Co	$Q_{Cu}$	Wt. % Co	$Q_{Cu}$
1.5*	+30.8	13.9	+29.1	70.3	+18.5
1.9	+32.1	23.6	+26.5	80.5	+17.6
3.1	+33.0	34.4	+25.9	90.4	+16.7
4.1*	+32.1	46.6	+20.8	100*	+27.37
6.7	+31.5	59.4†	+19.4		

All alloys contain traces of Fe and Ni.  $Q$  was measured after heating to  $160^\circ\text{C}$ .\* For  $0^\circ$  to  $100^\circ$ .

Co	1.5	4.1	100 %
a	+30.52	+31.03	+23.24
b	+0.776	+0.416	+ 8.26

† Contains 0.6% Fe.



## Co-Fe; see Fe alloys

Co-Ni; 0° t 1200°;  $Q_{Pt}$  (68)

Wt. % Co	a	b	c
10	-28.39	+9.944	-6.546

## Cr-Fe; see Fe alloys

Cr-Ni; 0° t 1200°;  $E_{Pt}$  (68)

Wt. % Cr	a	b	c
4.0	+22.43	+1.531	-1.914
5.0	+21.304	+1.716	-4.038
8.0	+28.47	+1.325	-1.492
10.0	+30.3	0.0	0.0
12.0	+19.9*	+2.8	
12.0	+31.28†	d = -1700	
16	+11.00‡	+7.70	-8.655
16	+30.22§	d = -3830	

\* 0° t 200°. † 200° t 1200°. ‡ 0° t 600°. § 600° t 1200°

## Cu-Hg; see Hg

Cu-Mn-Ni; 0° t 100°;  $E_{Pb}$  (17) manganin (84Cu, 12Mn, 4Ni) (?); a = +1.366, b = +0.0828, c = +3.36.Cu-Mn-Ni-Fe; \* t = 25°;  $Q_{Cu}$  (47)

Wt. %				Q
Cu	Mn	Ni	Fe	
88.02	9.93	1.71	0.24	+4
87.24	10.26	1.77	0.52	+5
88.20	8.84	1.78	0.93	+3
83.60	12.03	3.41	1.04	+8
84.72	12.83	2.08	0.73	+4

\* All specimens annealed.

Cu-Ni; 0° t 100°;  $Q_{Cu}$  (71)

At. % Ni	a	b	At. % Ni	a	b
5.4	-17.67	-4.55	66.4	-32.12	-2.47
10.8	-22.42	-6.69	69.6	-32.76	-1.58
21.4	-28.11	-7.73	73.0	-34.02	-1.48
32.1	-32.93	-7.71	74.5	-33.01	-0.71
41.9	-35.10	-7.74	74.7	-30.43	-2.36
50.9	-39.41	-8.66	82.8	-33.65	-1.66
55.1	-33.17	-6.75	88.3	-31.08	-3.84
62.8	-32.56	-5.95	100.0	-25.56	-3.40

For 3.94 Wt. % Ni, a = -15.14, b = +10.2; for 17.3 Wt. % Ni, a = -24.9, b = -13.2 (10).

Constantan = 60% Cu, 40% Ni; 0° t 400°, a = -38.105, b = -8.884, c = +8.568; error in  $E$  =  $\pm 1\%$  (2)Cu-Ni;  $t_1$  t  $t_2$ ;  $E_{Pt}$  (68)

Wt. % Cu	$t_1$	$t_2$	a	b	c
0.0	0	1200	-17.12	+2.460	-2.193
10.0	0	400	-30.85	+4.250	
	400	1200	-21.71		
30.0	0	300	-36.87	+4.712	
	300	1200	-39.37	d = +2980	
50.0	0	350	-53.23	+4.756	
	350	1200	-50.64	d = +1700	
70.0	0	400	-44.73	-0.978	
	400	1200	-49.80		

Cu-Ni; t = 50°;  $Q_{Pb}$  (34)

Wt. % Ni	$Q_{Pb}$	Wt. % Ni	$Q_{Pb}$	Wt. % Ni	$Q_{Pb}$
10.0	-22.0	41.8	-38.8	62.8	-31.5
15.5	-27.3	46.0	-38.8	89.3	-25.1
20.0	-29.0	49.0	-35.4	93.5	-23.0
24.5	-29.4	50.7	-35.8	100.0	-20.2
30.0	-33.3	56.0	-34.2		

Cu-Ni-Zn; -200° t +100°;  $E_{Pb}$ , German silver (commercial) (31); a = -10.861, b = -3.294, c = +1.893.Cu-P; t = 18°;  $Q_{Cu}$  (41)

Wt. % P	$Q_{Cu}$	Wt. % P	$Q_{Cu}$	Wt. % P	$Q_{Cu}$
1.88	+0.06	6.20	+1.40	13.97	+6.30
4.03	+0.435	8.75	+2.10	14.16*	+6.85
4.08	+0.48	12.70	+5.20	14.29	+4.30
5.75	+1.30	13.62	+6.00	14.56	+4.00

\* Cu<sub>3</sub>P.Cu-Sn; -80° t 100°;  $Q_{Pb}$  (56)

Vol. % Sn	a	b	Vol. % Sn	a	b
0	+3.57	+1.01	55	+2.07	+0.80
5	+0.81	+0.20	60	+2.43	+0.76
10	+0.66	+0.21	65	+2.45	+0.70
15	+1.17	+0.12	70	+1.30	+0.68
20	+1.25	+0.23	75	+1.47	+0.66
25	+0.86	+0.28	80	+1.06	+0.70
30	+0.49	+0.37	85	+0.41	+0.46
35	+2.13	+0.39	90	+0.31	+0.46
40	+1.54	+0.73	95	-0.10	+0.185
45	+1.58	+0.89	100	-0.13	+0.25
50	+2.18	+0.89			

Cu-Sn; 0° t 100°;  $Q_{Cu}$ ; for 5 Wt. % Sn, a = -3.46, b = +0.322 (10).Cu-Zn; \* -78° t 100°;  $Q_{Pb}$  (61)

Vol. % Zn	a	b	Vol. % Zn	a	b
0.0	+2.350	+1.38	59.5†	-0.062	+0.40
3.15	+0.707	+1.01	63.2	-1.082	+0.79
9.3	+0.608	+0.81	68.4	+0.639	+2.20
14.2	+0.710	+0.56	73.6‡	+3.330	+2.45
18.15	+0.740	+0.50	79.3	+2.195	+1.36
22.8	+0.702	+0.39	80.15	+1.407	+0.97
31.5	+0.602	+0.59	85.5	+1.821	+1.13
33.7	+0.699	+0.69	90.4§	+4.716	+1.75
39.3	+0.602	+0.59	93.7	+4.279	+1.54
41.7	+0.249	+0.60	95.0	+4.288	+1.72
47.7	+0.476	+0.44	98.8	+3.220	+1.69
53.2	+0.490	+0.62	100.0	+2.609	+1.49
53.4	+0.539	+0.73			

\* Electrolytic Cu; Zn free of As and Pb. † CuZn. ‡ CuZn<sub>2</sub>. § CuZn<sub>3</sub>.

Alloys of less than 45% Zn were annealed for 36 hr at temperature about 30° below transformation point; other alloys annealed at 650°C.

Cu-Zn; 0° t 100°;  $E_{Pb}$ , brass (commercial) a = +0.140, b = +0.5166 (59).

## Fe-C Steel; see Tables 4, 5

Fe-Co; \* t = 100°;  $E_{Cu}$  (37)

Wt. % Co	10.0	20.0	30.0
$E_{Cu}$	-0.64	-3.70	-3.50

\* Annealed by heating with electric current for 15 min; not over 2% difference between hard-drawn and annealed wires.

Fe-Cr; \* t = 100°;  $E_{Cu}$  (37); see also Table 4

Wt. % Cr	$E_{Cu}$	Wt. % Cr	$E_{Cu}$	Wt. % Cr	$E_{Cu}$
10.0	+1.20	20.0	+0.43	29.5	+0.31
18.0	+1.04	23.5	+0.32		

\* Annealed by heating with electric current for 15 min; not over 2% difference between hard-drawn and annealed wires.



Fe-Cr-Ni; \*  $t = 100^\circ$ ;  $E_{Cu}$  (37)

Wt. %				$E_{Cu}$
Cr	Ni	Si	C	
4.0	17.0	0	0	-0.12
10.0	20.0	0	0	-0.46
10.0	55.0	0	0	0.00
15.0	60.0	0	0	+0.07
20.0	55.0	0	0	+0.07
25.0	55.0	0	0	-0.08
7.0	75.5	0.03	0.22	+0.20
13.1	70.6	0.02	0.17	+0.20
13.1	70.6	0.02	0.20	+0.17
11.0	84.0	0.40	0.034	+1.49
15.6	80.4	0.58	0.23	+0.76

\* Annealed by heating with electric current for 15 min; not over 2% difference between hard-drawn and annealed wires.

Fe-Cr-Mn-Ni; \*  $t = 100^\circ$ ;  $E_{Cu}$  (37)

Wt. %					$E_{Cu}$
Cr	Mn	Ni	Si	C	
0.31	6.6	58.3	1.0	0.16	-0.94
0.11	12.0	82.8	1.058	0.068	-1.11
0.11	6.2	88.5	0.061	0.065	-1.60
31.9	0.20	57.7	0.30	0.40	-0.08
22.7	0.30	69.0	0.25	0.20	+0.24

\* Annealed by heating with electric current for 15 min; not over 2% difference between hard-drawn and annealed wires.

Fe-Cr-Mn-Ni;  $t_1$   $t_2$ ;  $E_{Pt}$  (60) nichrome (16Cr, 22.5Fe, 3Mn, 58.5Ni approximately)

$t_1$	$t_2$	a	d	$t_1$	$t_2$	a	d
0	420	+25.0		500	1082	-34.9	+6994

## Fe-Mn; see Table 4

Fe-Mn-Ni; \*  $t = 100^\circ$ ;  $E_{Cu}$  (37)

Wt. %		$E_{Cu}$	Wt. %		$E_{Cu}$
Mn	Ni		Mn	Ni	
3.0	10.0	-1.09	6.0	17.5	-0.73
2.0	12.0	-1.02	2.0	22.0	-1.84
2.0	17.0	-1.50	6.0	44.0	-0.59
3.0	17.0	-0.79			

\* Annealed by heating with electric current for 15 min; not over 2% difference between hard-drawn and annealed wires.

## Fe-Mo; see Table 4

Fe-Ni; \*  $t = 100^\circ$ ;  $E_{Cu}$  (37); see also Table 4

Wt. %			$E_{Cu}$	Wt. %			$E_{Cu}$
Ni	Si	C		Ni	Si	C	
0	0	0	+0.86	81.2	0.014	0.19	-2.45
17.0	0	0	-0.64	93.0	0	0	-1.90
20.0	0	0	-0.55	94.6	0.64	0.11	-1.40
30.0	0	0	-0.52	96.3	0.35	0.12	-2.00
33.5	0.16	0.25	-0.48	100.0	0	0	-2.38

\* Annealed by heating with electric current for 15 min; not over 2% difference between hard-drawn and annealed wires.

Fe-Ni;  $t = 48^\circ$ ;  $Q_{Cu}$  (49)

Wt. % Ni	$Q_{Cu}$	Wt. % Ni	$Q_{Cu}$	Wt. % Ni	$Q_{Cu}$
4.0	+2.32	21.0	+23.5	45.0	+29.0
7.0	+7.32	22.11	+21.0	47.08	+31.9
13.0	+16.9	26.4	+16.7	90.0	+17.9
14.0	+17.2	35.09	+9.79		
18.0	+21.0	40.0	+22.4		

\* If diameter of wire > 0.12 cm,  $Q$  is somewhat greater.

Fe-Ni;  $t_1$   $t_2$ ;  $E_{Pt}$  (68)

Wt. % Fe	$t_1$	$t_2$	a	b
10	0	750	-27.66	+7.326
	750	1200	+20.612*	

\* d = -15 600.

## Fe-Si; see Table 4

Fe-Ti; at  $50^\circ\text{C}$ ,  $Q_{Cu} = -140$  (52)

## Fe-W; see Table 4

Hg-Metal;  $20^\circ$  and  $t$ ;  $E_{Hg}$  (33)

Metal	At. *	$80^\circ$	$100^\circ$	$180^\circ$
Ag	1	+ 1.0	+ 1.2	+ 2.6
Bi	1	+ 59.6	+ 84.5	+203.6
Cd†	1	+ 7.9	+ 12.1	+ 28.2
Cu	1	+ 0.7	+ 0.8	+ 1.3
K	1	- 21.6	- 33.0	- 82.2
	8.47	-177.2	-273.4	-694.0
Li	0.253	- 13.9	- 22.4	- 43.4
	1	- 55.4	- 78.7	-184.8
Na	1	- 37.5	- 51.7	-117.1
	3.34	-114.2	-160.7	-389.0
Pb†	1	+ 25.6	+ 34.6	+ 82.5
Sb	1	+ 5.1	+ 7.5	+ 21.4
Sn	1	+ 19.9	+ 26.9	+ 65.8
Tl†	1	- 41.8	- 57.6	-138.8
Zn	1	+ 6.2	+ 9.2	+ 24.4

\* Atoms of metal per 100 atoms of Hg. † See Cd-Hg for  $Q_{Cu}$ . ‡ v. infra.

Hg-Pb;  $20^\circ$  and  $t$ ;  $E_{Hg}$  (33)

Wt. Pb*	$80^\circ$	$100^\circ$	$180^\circ$
	$E_{Hg}$		
1.03	+ 25.6	+ 34.6	+ 82.5
2.06	+ 35.5	+ 48.9	+110.1
3.09	+ 70.8	+120.8	+239.9
6.19	+ 92.0	+154.0	+548.3
9.28	+124.3	+162.6	+629.2
12.38	+ 94.2	+151.4	+529.9
15.47	+ 87.3	+148.2	+439.5
18.57	+ 96.6	+170.9	
24.77	+113.5	+179.6	+591.0
49.53	+147.2	+217.2	+656.9
98.2	+169.4	+250.3	+733.2
206	+216.5	+280.6	+746.7

\* Grams Pb per 100 g Hg; see also Hg-Metal.

Hg-Tl;  $20^\circ$  and  $t$ ;  $E_{Hg}$  (33)

Wt. Tl*	$80^\circ$	$100^\circ$	$180^\circ$
	$E_{Hg}$		
0.255	- 10.8	- 14.6	- 32.5
0.51	- 21.8	- 29.8	- 68.8
1.02	- 41.8	- 57.6	- 138.8
2.04	- 67.9	- 93.2	- 199.2
3.055	- 79.3	-111.0	- 250
4.08	- 86.6	-125.8	- 282.1
6.11	- 82.7	-114.3	- 246.8
12.22	- 44.4	- 65.3	- 120.7
24.44	+ 35.8	+ 52.2	+ 149.8
$\infty$ †	+321.7	+445.0	+1001.1

\* Grams Tl per 100 g Hg; see also Hg-Metal. † Pure Tl.

Ir-Pt; \*  $0^\circ$  to  $1200^\circ$ ;  $Q_{Pt}$  (39)

Wt. % Ir	a	b	c
5	+10.375	+0.250	-0.2344
10	+13.208	+0.750	-0.3906
15	+14.083	+1.063	-0.3906
20	+13.00	+1.875	-0.9375
25	+11.250	+2.250	-1.1718
30	+10.75	+2.375	-0.9375
35	+10.50	+2.375	-0.9375

\* Alloy in all proportions.



**Mn-Ni;  $t_1$  t  $t_2$ ;  $E_{Pt}$  (68); Wt. % Mn = 5**

$t_1$	$t_2$	a	b
0	400	-2.158	+6.58
400	1200	-0.375	d = -3220

**Mo-Ni;  $0^\circ$  t  $1200^\circ$ ;  $Q_{Pt}$  (68)**

Wt. % Mo	a	b	Wt. % Mo	a	b
4	+11.85	+1.2056	12	+27.45	+1.788
5	+14.90	+1.48	16	+27.45	+2.00
8	+21.08	+1.784	20	+23.38	+2.392
10	+24.70	+1.720			

**Nichrome; see Fe-Cr-Mn-Ni**

**Ni-Ta;  $150^\circ$  t  $1200^\circ$ ;  $E_{Pt}$  (68); for 5 Wt. % Ta, a = -0.573, d = -1914**

**Ni-Ti;  $t_1$  t  $t_2$ ;  $E_{Pt}$ ; Wt. % Ti = 5 (68)**

$t_1$	$t_2$	a	b
0	600	-7.98	+1.256
600	1200	-1.117	d = -1860

**Ni-V;  $0^\circ$  t  $1200^\circ$ ;  $Q_{Pt}$  (68)**

Wt. % V	a	b	Wt. % V	a	b
5	+18.30	+1.72	10	+26.5	+1.56

**Ni-W;  $0^\circ$  t  $1200^\circ$ ;  $Q_{Pt}$  (68)**

Wt. % W	a	b	Wt. % W	a	b
4	+1.428	+0.885	12	+12.26	+1.906
5	+2.90	+1.08	16	+16.38	+1.96
8	+6.91	+1.664	20	+20.22	+2.128
10	+9.70	+1.72			

**Ni-Zr;  $0^\circ$  t  $1200^\circ$ ;  $Q_{Pt}$  (68); for 5 Wt. % Zr, a = -12.57, b = +2.286**

**Pb-Sb;  $0^\circ$  t  $150^\circ$ ;  $Q_{Cu}$  (69)**

Wt. % Sb	a	b	Wt. % Sb	a	b
0.0	-2.83	-0.94	50.0	+2.11	+2.08
5.0	-1.68	-1.10	70.0	+2.15	+3.80
13.0	-1.54	-0.44	90.0	+4.23	+6.54
30.0	+0.33	+1.34	100.0	+37.53	+7.74

**Pb-Sn;  $0^\circ$  t  $150^\circ$ ;  $Q_{Cu}$  (69)**

Wt. % Sn	a	b	Wt. % Sn	a	b
0	-2.83	-0.94	50	-2.67	-1.06
5	-2.63	-0.94	80	-3.13	-0.54
30	-2.80	-0.80	100	-2.73	-1.34

**Pb-Tl;  $0^\circ$  t  $180^\circ$ ;  $Q_{Pb}$  (33); for 2.03 Wt. % Tl, a = -0.0120, b = -0.0742**

**Pb-Zn;  $0^\circ$  t  $180^\circ$ ;  $Q_{Pb}$  (33); for 0.63 Wt. % Zn, a = +0.0040, b = +0.016**

**Pd-Pt;  $0^\circ$  t  $1200^\circ$ ;  $Q_{Pt}$  (39)**

Wt. % Pt	a	b	c
0	-3.875	-1.350	-0.234
10	+4.042	-0.563	-0.781
20	+6.792	+0.438	-1.250
30	+7.583	+0.938	-0.885
40	+7.000	+1.375	-0.938
50	+7.167	+1.188	-0.677
60	+5.833	+1.500	-0.729
70	+5.125	+1.135	-0.469
80	+4.875	+0.812	-0.469
90	+3.625	+0.395	-0.234

\* Alloy in all proportions.

**Pt-Rh;  $0^\circ$  t  $1600^\circ$   $Q_{Pt}$ ; see also Vol. I, p. 57; error in  $E_{Pt}$  may amount to  $\pm 50$**

Wt. % Rh	a	b	c	Lit.
1	+2.19	-0.044	+0.024	(29)
5	+5.99	+0.200	-0.060	(29)
10	+7.013	+0.640	-0.1932	(29)
10*	+7.048	+0.5896	-0.1284	(80)
15	+6.69	+1.072	-0.3276	(29)
20	+6.083	+1.380	-0.3999	(29)
30	+6.12	+1.344	-0.1092	(46)
40	+6.44	+1.344	-0.0468	(46)
100	+6.27	+1.612	-0.1797	(45)

\* Le Chatelier's couple.

**Pt-Rh;  $t_1$  t  $t_2$ ;  $E_{Pt}$ ; Rh, Wt. % = 10; error in  $E$  may amount to  $\pm 50$**

$t_1$	$t_2$	a	b	c	Lit.
-253	0	+5.97	+4.28		(80)
0	+650	+5.543	+1.804	-1.965	(80)
+650	1600	+8.162	+0.338	d = -283.5	(80)
+250	1600	+8.048	+0.344	d = -310	(45)
+400	1100	+8.259*	+0.3332	d = -313.8	(21)

\* Made by Heraeus; diameter = 0.4 mm.

**Pt-Ru;  $250^\circ$  t  $1500^\circ$ ;  $E_{Pt}$   $\pm 5$  (45); for 10 Wt. % Ru, a = +9.260; b = +0.300, d = -359**

**Sb-Sn;  $t = 30.1^\circ$ ;  $Q_{Pb}$  (48)**

Wt. % Sb	$Q_{Pb}$	Wt. % Sb	$Q_{Pb}$	Wt. % Sb	$Q_{Pb}$
20	+1.07	60	+12.54	90	+7.77
30	+2.16	70	+12.20	95	+7.93
50	+6.14	80	+14.08	100	+32.67

**Sb-Te;  $t = 18^\circ$ ;  $Q_{Cu}$  (41)**

Wt. % Sb	$Q_{Cu}$	Wt. % Sb	$Q_{Cu}$	Wt. % Sb	$Q_{Cu}$
2	+139.0	35	+62.3	70	+2.3
5	+105.0	38.90*	+82	75	+1.6
10	+93.0	40	+34.0	80	+1.0
13	+86.5	45	+13.5	83	+3.5
15	+81.7	50	+9.3	90	+6.5
20	+74.0	55	+8.0	95	+10.0
25	+63.0	60	+4.5		
30	+61.2	65	+3.0		

\* Sb<sub>2</sub>Te<sub>3</sub>.

**SeSn;  $E_{Pt}$  is of same order of magnitude as for Se<sub>2</sub>Sn but is of opposite sign (65)**

**Se<sub>2</sub>Sn;  $0^\circ$  t  $650^\circ$ ;  $E_{Pt}$  (1  $\pm$  0.025); a = +389.5, b = +6.334 (65)**

**Se-Te;  $t = 18^\circ$ ;  $Q_{Cu}$  (1  $\pm$  0.03) (41)**

Wt. % Se	$Q_{Cu}$	Wt. % Se	$Q_{Cu}$	Wt. % Se	$Q_{Cu}$
2.0	+480	15	+680	40	+620
5	+570	20	+580	45	+580
10	+563	30	+540	50	+460

**Sn-Te;  $t = 18^\circ$ ;  $Q_{Cu}$  (41)**

Wt. % Sn	$Q_{Cu}$	Wt. % Sn	$Q_{Cu}$	Wt. % Sn	$Q_{Cu}$
10	+116.0	45	+22.3	70	-0.2
15	+84.0	48.28*	+26.0	80	-0.8
20	+71.0	49	+99.0	85	-1.35
30	+42.2	50	+6.3	90	-1.5
35	+34.0	55	+1.6	95	-1.4
40	+28.0	60	+0.7	100	-2.25

\* SnTe.



Sn-Zn; 0° t 150°;  $Q_{Cu}$  (69)

Wt. % Sn	a	b	Wt. % Sn	a	b
0	+0.20	0.0	70	-1.43	-0.94
10	-0.23	-0.14	90	-2.37	-0.66
30	-1.39	+0.18	95	-2.57	-0.66
50	-1.23	-0.46	100	-2.73	-1.34

## Commercial Alloys and Miscellaneous Mixtures

"Akkumulatorenlot" (75Pb, 20Hg, 5Sb), 0° t 300°,  $E_{Constantan} = 4.18 t$  (25)

## Brass; see Cu-Zn

## Chronin (80)

$t, ^\circ C$	-78.5	-170.3	-188.8	-252.7
$E_{Pb}$	+1277	+2435	+2612	+3025

## Constantan; see Cu-Ni

## Culmitz (80)

$t, ^\circ C$	$E_{Pb}$	$t, ^\circ C$	$E_{Pb}$
-78.4	+204	-192.6	+401*
	+160*	-252.7	+596
-192.6	+476		+472*

\* After annealing.

## German Silver; see Cu-Ni-Zn

## Kruppin (80)

$t, ^\circ C$	-78.5	-170.3	-188.8	-252.7
$E_{Pb}$	-280	-992	-1129	-920

## Manganin; see Cu-Mn-Ni

Nernst filament; 980° t 1425°;  $Q_{Pt}$ ; a = +405 (72)

## Nichrome; see Fe-Cr-Mn-Ni

## Nickelin (80)

$t, ^\circ C$	$E_{Pb}$	$t$	$E_{Pb}$
-78.4	-1256	-192.6	-2416*
	-1259*	-252.7	-2650
-192.6	-2406		-2600*

\* After annealing.

## Piano wire; see Table 4

Platinoid; -200° t 100°;  $E_{Pb}$ ; a = -10.620, b = -2.766, c = +3.171 (31)

## Resistin (80)

$t, ^\circ C$	-78.5	-170.3	-188.8	-252.7
$E_{Pb}$	+331	+652	+713	+895

Steel; see Al-Fe, Fe, and Tables 4, 5

TABLE 4.—MEAN THERMOELECTRIC POWER ( $E/t$ ) BETWEEN 0 AND  $t^\circ$ : STEELS,  $t = -78.5$  AND  $+100^\circ$  (32)

For other alloys of Fe, see Tables 3, 5.  $E = at + \frac{1}{2}bt^2(10)^{-2} + \frac{1}{3}ct^3(10)^{-3}$ ;  $Q = a + bt(10)^{-1} + ct^2(10)^{-2}$ . An. = annealed; Qu. = quenched; " $t_1 t_2$ " denotes that  $t$  lies between  $t_1$  and  $t_2$ . Except where the contrary is indicated, one junction is at 0°C and the other at  $t, ^\circ C$ . Steels of low C content were annealed in magnesia; those of about 0.8% C, in turnings of pig iron. Mean error in all cases = ca. 30  $\mu V$  (= 30 microvolt). Unit of  $E = 1 \mu V = 10^{-6}$  volt; of  $Q$  and  $E/t = 1 \mu V/^\circ C = 10^{-6}$  volt per  $1^\circ C$ ;  $t$  = centigrade temperature,  $^\circ C$ .

Symbol	Composition in %						$E_{Pb}/t$					
	C	Mn	P	S	Si	Al	Annealed		Quenched		Ingot	
							-78.5°	+100°	-78.5°	+100°	-78.5°	+100°
Al steels; <i>see also</i> Table 3; An. from 900°C, cooling 8.75 hr; Qu. at 1000°C in water at 14°C*												
1A2	0.17	Tr.	0.008	0.022	Tr.	2.04	- 7.65	-12.65	- 8.26	-11.50		
1A3	0.13	Tr.	0.016	0.013	0.10	3.04	-11.93	-12.65	-11.93	-10.05		
1A7	0.08	0.05	0.020	0.017	0.18	7.20	-16.92	-12.65	-17.32	-10.05		
8A5	0.81	0.12	0.024	0.024	0.22	4.6	-10.20	-14.65	-13.86	-16.30		
8A7	0.66	0.14	0.025	0.050	0.26	7.0	-11.52	-16.05	-15.90	-16.30		
8A10	0.67	0.09	0.034	0.024	0.11	9.1	-15.40	-16.05	-14.90	-16.30		
8A15	0.86	0.40	0.032	0.018	0.23	14.9	- 8.77	-13.15	-13.03	-14.05		
C steels; <i>see also</i> Tables 3, 5; An. from 900°C, cooling 8.5 hr; Qu. at 950°C in water at 15°C*												
H1	0.07	0.03	0.005	0.013	0.00		+11.93	+ 8.55	+12.59	+ 8.73		
H2	0.24	0.03	Tr.	0.015	0.03		+11.11	+ 7.65	+ 9.99	+ 6.93		
H3	0.44	0.08	Tr.	0.016	0.05		+ 9.68	+ 6.20	+ 5.20	+ 3.46		
H4	0.79	0.09	0.006	0.009	0.00		+ 8.05	+ 5.40	+ 0.92	- 1.32		
H5	1.12	0.06	Tr.	0.022	0.02		+ 6.02	+ 4.10	- 5.25	- 5.70		
H6	1.58	0.09	Tr.	0.016	0.04		+ 6.73	+ 4.15	- 6.52	- 5.80		

For H1 to H5, coefficients of  $Q_{Cu}$  are: 0° t 700°, a = A, b = -0.563A, c = +0.5A, where A = 18.8 - 10.5C + 4.1C<sup>2</sup>, carbon content = C%;  $t_2 t_3$ , a = -5.9 - 0.01bt<sub>2</sub>, b = -0.38;  $t_2 t_3$  1000°, a = -10.5 - 0.01bt<sub>2</sub>, b = -2.8;  $t_2, t_3$  = temperatures of transformations A<sub>2</sub>, A<sub>3</sub> (18). For pure Fe,  $t_2 = 730^\circ$ ,  $t_3 = 950^\circ$ ; increasing C decreases both; with more than 0.4% C they coincide at ca. 700° (18). For piano wire, coefficients of  $E_{Pb}$  -200° t 100° are: a = +10.763, b = -1.5586, c = -18.762 (31).

Cr												
Cr steels; <i>see also</i> Table 3; An. from 1000°C, cooling 7 hr; Qu. at 1000°C in water at 11°C*												
1C1	0.06	Tr.	0.016	Tr.	0.70	1.20	+17.87	+16.93	+ 6.83	+16.4	+17.43	+16.6
1C2	0.08	0.08	0.015	Tr.	0.12	1.89	+15.72	+16.65	+14.78	+15.20	+15.51	+16.6
1C3	0.28	0.15	0.010	Tr.	0.05	2.66	+17.28	+18.11	+14.88	+21.50	+14.99	+17.10
1C7	0.07	Tr.	0.010	0.014	0.12	7.84	+ 9.94	+14.92	+ 9.99	+13.50	+ 8.67	+12.70
1C10	0.42	Tr.	0.010	Tr.	0.35	9.80	+12.40	+14.74			+ 6.97	+ 5.82
1C12	0.14	Tr.	0.016	0.015	0.21	13.60	+ 6.63	+10.56	+ 5.20	+ 7.65	+ 6.27	+ 8.73
1C25	0.24	0.10	0.022	0.013	0.26	25.31	+ 6.38	+ 9.01	+ 6.40	+ 5.09	+ 4.25	+ 6.28
1C30	0.46	Tr.	0.024	0.006	0.37	31.75	+ 4.37	+ 6.55	+ 5.09	+ 7.86	+ 6.03	+ 9.55
8C1	0.97	0.24	0.013	0.016	0.22	0.92	+ 9.93	+ 8.92	+ 3.97	+ 3.64	+ 9.70	+ 8.83



TABLE 4.—(Continued)

Symbol	Composition in %						$E_{Pb}/t$					
	C	Mn	P	S	Si	Cr	Annealed		Quenched		Ingot	
							-78.5°	+100°	-78.5°	+100°	-78.5°	+100°
Cr steels; see also Table 3; An. from 1000°C, cooling 7 hr; Qu. at 1000°C in water at 11°C*												
8C2	0.89	0.10	0.020	0.033	0.28	2.14	+10.41	+ 9.64	+ 3.59	+ 4.20	+ 9.70	+ 9.00
8C5	0.79	Tr.	0.016	0.023	0.42	4.57	+12.40	+12.56	+ 7.13	+ 5.91	+12.53	+12.90
8C7	0.84	0.05	0.018	0.031	0.41	7.27	+11.82	+13.45			+10.40	+11.90
8C10	0.52	0.13	0.024	0.005	0.62	9.85	+11.70	+14.48	+ 5.08	+ 3.58	+ 2.83	+ 3.63
8C12	0.96	0.05	0.013	0.047	0.41	11.52	+10.60	+13.60	+ 7.03	+ 9.70	+ 9.60	+11.90
8C20	0.90	0.05	0.010	0.007	0.74	18.65	+ 5.09	+ 7.95	+ 3.31	+ 4.64	+ 0.83	- 1.55
8C25	0.82	0.05	0.016	0.008	0.58	26.54	+ 3.36	+ 5.91	+ 2.04	+ 4.64	+ 2.90	+ 5.37
8C30	0.92	0.05	0.021	0.012	0.47	32.46	+ 6.97	+ 6.30	+ 4.40	+ 5.55	+ 4.95	+ 6.28
Mn steels; An. from 900°C, cooling 5 hr; Qu. at 1000°C in water at 14°C*												
8M0.5	0.87	0.40	0.020	0.024	1.35		- 0.30	- 3.10		- 2.00		
8M1	0.84	1.03	0.024	0.015	0.57		- 0.71	- 2.80	- 5.50	- 6.65		
8M3	0.93	3.08	0.015	0.010	1.44		- 2.65	- 4.70				
8M12	0.96	12.09	0.011	0.013	0.87		- 9.78	-11.80	-10.20	- 6.65		
	1.2	5.0	Ni =	Hadfield's Mn steel; for $E_{Fe}$ , $0^\circ t 310^\circ$ , $a = +21.8$ , $b = -5.8$ ; for $310^\circ < t < 1100^\circ$ , $E_{Fe} = +3975 \pm 50$ (5)								
	(?)	12	(?)	Hadfield's Mn steel; for $E_{Pb}$ , $-200^\circ t +100^\circ$ ; before annealing, $a = -5.591$ , $b = -0.5152$ , $c = +0.390$ ; after An. from $600^\circ$ , $a = -5.067$ , $b = -0.3582$ , $c = +2.337$ (31)								
Mo steels; An. from 900°C, cooling 8.75 hr; Qu. at 1000°C in water at 14°C*												
1Mo0.5	0.19	0.07	0.018	0.009	0.12	0.45	+10.20	+ 8.35				
1Mo1	0.16	0.10	0.018	0.032	0.11	1.00	+11.01	+ 7.70	+10.20	+ 8.00		
1Mo2	0.14	0.17	0.021	0.009	0.12	2.20	+10.90	+ 7.80	+10.30	+ 7.92		
1Mo5	0.29	0.50	0.026	0.039	0.12	4.50	+ 8.77	+ 6.30	-12.23	+ 3.98		
8Mo0.5	0.78	0.26	0.021	0.032	0.21	0.50	+ 4.59	+ 3.00	- 4.48	- 6.50		
8Mo1	0.81	0.40	0.040	0.018	0.02	1.21	+ 4.79	+ 3.20				
8Mo2	0.81	0.30	0.016	0.034	0.017	1.98	+ 5.30	+ 4.30	+ 1.12	+ 0.10		
Ni steels;† see also Table 3; An. from 900°C, cooling 7 hr; Qu. at 950°C in water at 18°C*												
1N2	0.07	0.02		0.006	0.07	2.23	+ 9.07	+ 6.3	+10.91	+ 6.2	+ 8.97	+ 6.5
1N5	0.12	0.01		0.004	0.05	5.23	- 0.61	- 3.5	+ 0.2	- 3.4	- 0.61	- 3.2
1N7	0.12	0.12		0.005	0.05	7.13	- 4.89	- 7.8	- 4.99	- 7.6	- 4.89	- 7.6
1N10	0.13	Tr.		0.005	0.10	10.10	-10.8	-14.6	-11.11	- 9.7	-11.21	-13.5
1N12	0.12	Tr.		0.002	0.09	12.07	-14.58	-16.9	-14.78	-17.0	-13.45	-17.4
1N15	0.11	Tr.		0.004	0.02	15.17	-19.38	-23.5	-18.75	-23.9	-20.28	-24.3
1N20	0.18	Tr.		0.004	0.02	20.40	-28.96	-30.4	-33.22	-31.3	-27.83	-30.0
1N25	0.16	Tr.		0.007	0.04	25.85	-32.0	-11.5	-33.22	-31.3	-31.08	-27.8
1N30	0.12	Tr.		Tr.	0.03	30.00	-15.08	- 6.9	-14.98	- 1.0	-15.49	- 1.5
4N2	0.21	0.02		Tr.	0.03	1.97	+ 8.66	+ 7.0	+ 8.05	+ 5.5	+ 8.25	+ 6.3
4N5	0.20	0.02		0.03	0.04	4.90	+ 1.73	- 2.4	+ 0.71	+ 2.0	+ 0.0	- 2.3
4N7	0.23	0.05		Tr.	0.08	7.59	+ 4.18	- 7.3	- 3.26	- 6.0	- 4.38	- 6.8
4N10	0.21	0.02		Tr.	0.01	9.79	+ 9.88	-12.6	- 9.88	-11.6	- 9.58	-12.9
4N12	0.22	0.02		0.002	0.01	12.29	+13.25	-15.3	-11.92	-15.7	-13.67	-16.4
4N15	0.22	Tr.		0.002	0.05	15.04	+16.61	-27.3	-16.31	-19.1	-17.63	-10.6
4N20	0.22	0.02		0.003	Tr.	20.01	+22.87	-30.6	-22.43	-23.7	-22.43	-21.5
4N25	0.23	0.02		0.003	0.08	25.06	+17.73	- 7.1	-19.98	-12.7	-14.88	- 3.8
4N30	0.19	0.02		0.002	0.03	27.87	+ 8.05	- 2.3	- 9.37	- 0.9	- 4.18	- 1.9
9N2	0.80	0.10		0.005	0.10	2.30	+ 6.52	+ 4.7	+ 5.91	+ 4.6	+ 5.81	+ 4.6
9N5	0.78	0.09		0.004	0.08	4.90	+12.53	- 3.0	- 1.02	- 2.6	- 1.02	- 2.6
9N7	0.81	0.12		0.003	0.10	7.09	- 5.10	- 6.9	- 4.18	- 5.9	- 3.97	- 5.9
9N10	1.05	0.10		0.004	Tr.	9.79	- 7.34	- 8.5	- 7.24	- 8.5	- 8.15	- 8.7
9N12	0.76	0.09		0.004	0.09	12.27	- 7.95	- 9.4	- 8.87	- 9.8	-10.30	-10.4
9N15	0.80	0.06		0.007	0.09	15.04	-12.13	-11.1	-10.30	-10.1	- 9.38	- 4.9
9N20	0.80	0.02		0.003	0.09	20.01	-12.53	- 6.6	- 5.10	- 5.0	- 6.93	- 3.5
9N25	0.79	0.07		0.002	Tr.	25.06	-12.43	- 6.1	- 4.69	- 4.9	- 2.95	- 2.6
9N30	0.81	0.03		0.004	0.14	29.96	- 5.71	- 1.8	- 3.36	- 2.0	- 2.95	- 1.9



TABLE 4.—(Continued)

Symbol	Composition in %						$E_{Fe}/t$					
	C	Mn	P	S	Si	Ni	Annealed		Quenched		Ingot	
							-78.5°	+100°	-78.5°	+100°	-78.5°	+100°
Si steels; An. from 900°C, cooling 5 hr; Qu. at 1000°C in water at 14°C*												
1S0.5	0.21	0.72	0.117	0.061	0.41		+ 2.14	- 0.30	+ 1.12	- 0.90		
1S1	0.21	Tr.	0.024	0.020	0.93		- 2.95	- 6.10	- 1.32	- 5.00		
1S2	0.18	0.27	0.032	0.012	1.60		- 4.89	- 8.28	- 5.10	- 8.40		
1S3	0.28	0.38	0.034	0.009	5.12		- 6.93	-10.80	- 7.03	-10.40		
8S1	0.84	0.57	0.021	0.017	1.16		- 3.46	- 6.00				
8S2	0.83	0.41	0.021	0.017	1.15		- 6.93	- 9.90	- 7.85	-10.20		
8S3	0.94	1.44	0.062	0.017	5.54		- 8.36	-12.00	- 9.07	-10.70		
						W						
W steels; An. from 900°C, cooling 8.5 hr; Qu. at 1000°C in water at 14°C*												
1T0.5	0.18	Tr.	0.013	Tr.	0.03	0.41	+ 9.18	+ 6.30	+ 8.56	+ 5.70		
1T1	0.11	Tr.	0.016	0.005	0.06	0.93	+ 8.56	+ 5.98	+ 7.85	+ 5.65		
1T2	0.11	Tr.	0.010	0.008	0.03	1.75	+ 7.75	+ 5.24	+ 6.83	+ 4.75		
1T5	0.13	Tr.	0.015	Tr.	0.03	4.96	+ 7.95	+ 6.25	+ 7.34	+ 5.20		
1T15	0.20	Tr.	0.013	0.008	0.06	14.37	+ 7.75	+ 6.40	+ 7.95	+ 7.40		
1T20	0.22	Tr.	0.011	0.013	0.14	20.71	+ 8.00	+ 6.30	+ 8.05	+ 7.25		
8T0.5	0.86	0.027	0.012	0.033	0.04	0.40	+ 1.84	- 0.08	- 1.63	- 4.15		
8T2	0.66	0.054	0.015	0.023	0.12	1.95	+ 2.55	+ 0.50	+ 1.12	- 1.70		
8T10	0.81	Tr.	0.015	0.014	0.09	9.99	+ 5.00	+ 3.00	+ 2.85	+ 1.30		
8T15	0.71	Tr.	0.015	0.023	0.12	14.74	+ 2.75	+ 0.60	+ 2.85	- 1.40		

\* An. = annealed, time in furnace = 3 hr, time of cooling is as indicated. Qu. = quenched, specimen in furnace 11 or 12 min and for 2 min was at temperature indicated.

† For 1N and 4N groups, changes in heat treatment produce slight effect; maximum negative value of  $E$  occurs at ca. 25 % Ni in 1N and ca. 20 % Ni in 4N group.

TABLE 5.—THERMOELECTROMOTIVE FORCE ( $E$ ) OF CARBON STEELS: EFFECT OF HEAT TREATMENT (23); see also Table 4

Specimens were quenched at 903 or 908°C, kept at 97 to 102°C for 48 hr, then heated (drawn) to temperature indicated and kept at that temperature for 1 to 2 hr, then allowed to cool slowly in furnace. Error in  $E$  not greater than 10  $\mu$ v. For all 8 specimens, the smallest negative value of  $E$  corresponds to drawing temperature of 696°C. Unit of  $E = 1 \mu$ v =  $10^{-6}$  volt; of admixture = 1%; temperature, °C.

Sym- bol	Admixture					Quenched		Drawn							
						903°	908°	100°	205°	309°	388°	495°	599°	696°	800°
	C	Mn	P	S	Si	$E_{IN_2}$ (junctions at 0° and 100°C)									
C04	0.04	0.10	0.007	0.029			- 74	- 36	- 34	- 29	- 34	- 29	- 29	- 26	- 29
M16	0.30	0.204	0.012	0.013	0.033		-310	-278	-230	-170	-136	-102	- 94	- 83	-100
H35	0.35	0.08	0.009	0.024	0.18		-575	-537	-499	-452	-437	-419	-414	-400	-413
H41	0.41	0.08	0.012	0.016	0.19		-615	-578	-529	-474	-444	-434	-429	-414	-420
H57	0.57	0.11	0.010	0.020	0.17		-707	-627	-537	-474	-444	-419	-414	-394	-417
C4	0.76	0.221	0.016	0.041	0.169	- 950		-718	-577	-474	-439	-410	-404	-350	-393
C5	0.945	0.189	0.013	0.061	0.155	-1170		-795	-608	-458	-410	-392	-376	-364	-378
C7	1.05	0.190	0.013	0.020	0.167	-1308		-916	-713	-556	-516	-509	-497	-467	-473
IN2	0.018	0.011	0.006	0.018	Cu = 0.018 = pure ingot iron = reference metal										

TABLE 6.—THERMOELECTRIC POWER ( $Q$ ) OF OXIDES AND SULFIDES

$R$  = reference metal,  $Q_R = a + bt$  if  $t$  lies between  $t_1$  and  $t_2$ . Unit of  $Q = 1 \mu$ v/°C =  $10^{-6}$  volt/°C;  $t_1$ ,  $t_2$  = centigrade temperature, °C.

Oxide	$R$	$t_1$	$t_2$	$a$	$b$	Lit.	Oxide	$R$	$t_1$	$t_2$	$a$	$b$	Lit.
Bi <sub>2</sub> O <sub>3</sub>	Pb†	500	800	+ 1 946	- 1.86	(11)	FeS <sub>2</sub>	Cu	50	50	$Q_{Ca} = + 200$		(52)
CdO	Pb†	100	1 065	- 32	- 0.030	(11)	Mn <sub>2</sub> O <sub>3</sub>	Pb†	200	1 200	+ 628	- 0.332	(11)
Co <sub>3</sub> O <sub>4</sub>	Pb†	200	1 200	+ 629	- 0.221	(11)	MnO <sub>2</sub> H <sub>2</sub>	Cu	50	50	$Q_{Ca} = + 200$		(52)
Cr <sub>2</sub> O <sub>3</sub>	Pb†	950	1 285	- 704	+ 0.432	(11)	MoS	Cu	50	50	$Q_{Ca} = + 770$		(52)
CuO	Pb†	170	850	- 1 029	+ 1.715	(11)	NiO	Pb†	400	1 200	+ 254	- 0.065	(11)
	Cu*	0	700	+ 1 190	- 0.38	(20)	PbO	Pb†	250	390	-48 300	+117.2	(11)
Cu <sub>2</sub> O	Cu*	0	700	+ 1 052.5	- 0.75	(20)		Pb†	390	550	- 6 000	+ 9.22	(11)
FeO	Cu	50	50	$Q_{Ca} = + 500$		(52)		Pb†	550	850	- 3 914	+ 5.43	(11)
Fe <sub>2</sub> O <sub>3</sub>	Cu	50	50	$Q_{Ca} = + 60$		(52)	SnO	Pb†	0	1 200	- 90	- 0.437	(11)
Fe <sub>3</sub> O <sub>4</sub>	Pb†	170	875	- 54.6	- 0.026	(11)	U <sub>2</sub> O <sub>8</sub>	Pb†	65	1 265	+ 96	- 0.157	(11)
	Pb†	875	1 485	- 53.2	- 0.018	(11)	WO <sub>3</sub>	Pb†	140	970	- 18.4	- 0.053	(11)
	Fe*	0	700	- 427	0.00	(20)	ZnO	Pb†	355	1 350	- 735	+ 0.259	(11)
FeS	Cu	50	50	$Q_{Ca} = - 26$		(52)							

\* Error in  $E = \pm 200$  microvolt. † Used Pt as reference metal, but expressed results in terms of  $Q_{Pb}$ .



TABLE 7.—EFFECT OF STRESS UPON THERMOELECTRIC PROPERTIES OF METALS

$\mathcal{E}_0$  = thermo emf around a circuit composed of two specimens of the same material, one specimen (s) is stressed, the other (o) not stressed; one junction is at 0°C and the other is at  $t$ , °C;  $\mathcal{E}_0$  is positive if the current flows from the stressed to the unstressed specimen at the junction at 0°C.

If  $p$  = hydrostatic pressure upon the stressed specimen;  $\tau$  = longitudinal tension upon the stressed specimen;  $t$  = temperature (°C);  $f, g, h, m, n$  are constants depending upon the metal; then if  $\tau = 0$ ,  $\mathcal{E}_0 = fpt\{1 + gp(10^{-6})\}\{1 + ht(10^{-3})\}$ ;  $\mathcal{Q}_0 = kp$ , where  $k = f\{1 + gp(10^{-6})\}\{1 + 0.5ht(10^{-3})\}$ ;  $k = f$  if  $g = 0, h = 0$ . If  $p = 0$ ,  $\mathcal{E}_0 = 1000m\tau + n\tau^2$ .

The numbers in the "Error" column indicate the probable uncertainty in the value of  $\mathcal{E}_0$ . Unit of  $\mathcal{E} = 1\mu\text{v} = 10^{-12}$  volt; of  $p$  and  $\tau = 1 \text{ kg/cm}^2 = 14.22 \text{ lb./in.}^2 = 0.968 \text{ A}_n$ ; of "Error" =  $10^{-6}$  volt;  $t$  = centigrade temperature, °C.

Symbol	Tension (17)*			Pressure (17)†				$\mathcal{Q}_0$ (78)‡
	$t$	$m$	$n$	$f$	$g$	$h$	Error	
Ag.....				+ 8.34	- 6.8	+1.47	±0.02	+ 8.7
Al.....	50.5	+ 8.8	- 6.7	See Table 8				- 0.59
	76	+ 8.8	- 4.7					
Au.....				+ 4.40	- 8.2	+2.0	±0.01	+ 4.61
Bi.....				+513	+37.4	-0.06	±4	+707§
Brass.....	52	- 0.22	+ 0.03					
	77	- 0.13	+ 0.012					
	94	- 0.47	+ 0.05					
Cd.....				+ 21.3	+ 6.0	+6.3	±0.5	+ 36.3
Co.....				- 14.4	- 1.43	+2.07	±5%	
Constantan  .....				+ 27.9	0	+0.62	±0.1	+ 28.7
Cu.....	95	+ 0.56		+ 2.58	- 2.2	+1.9	±0.15	+ 3.15
Fe.....	52	+12.0¶	-23.5	See Table 8				+ 12.5
	95	+22.3¶	-42					
Hg**.....						$t =$ 20-80 106-151 114-167 228-270 250-300 304-346 0-100		+194 +294 +340 +478 +466 +449 +234
Manganin.....		Variable††		- 1.31	0	-1.57	±0.04	- 8.5
Mg.....				- 8.2	+26.0	0	±0.02	- 8.9
Mo.....				+ 0.099‡‡	0	+278.0-2.18§		
Ni.....	31	+ 3.35	- 0.60	‡ 6.11	+16.5	+3.06	±0.015	+ 9.6
	51	+ 5.77	- 1.32					
	77.5	+ 8.1	- 1.75					
	94.5	+12.1	- 3.7					
Pb.....				+ 4.09	0	+2.9	±0.01	+ 5.6
Pd.....				+ 20.8	+ 1.07	+0.5	±0.1	+ 23.7
Pt.....				+ 13.94§§	0	+9.64-0.0676‡		+ 18.6
				+ 14.3	+15.6	+0.87	±0.17	
Sn.....				See Table 8				- 0.95§
Tl.....								
W.....				+ 44.4	-17.0	+2.4	±0.2	
Zn.....				+ 10.86	0	+1.61	±0.1	
				+ 59.3	0	+2.23	±0.2	
						$t = 43$		+ 39
						$t = 58$		+ 57

\* For  $\tau$  between 0 and  $\tau_m$ ; values of  $\tau_m$  and of error in  $\mathcal{E}_0$  as follows:

Metal.....	Al	Fe	Cu	Ni	Brass	Manganin
$\tau_m$ .....	(?)	500	700	2000	2800	1300
Error.....	±5%	±5%	±10%	±2.5%	±8%	

† Range in  $p$  2 000 to 12 000 kg/cm<sup>2</sup>; in  $t$  is 0 to 100°C.

‡ Range in  $t$  is 0 to 100°C, in  $p$  is 1 to 300 kg/cm<sup>2</sup> (78), probable error in  $\mathcal{Q}_0$  ca. 1.5%; for (74)  $t \leq 400^\circ\text{C}$ ,  $p \leq 55 \text{ kg/cm}^2$ ; probable error in  $\mathcal{Q}_0$  ca. ±3%.

§ For liquid metal,  $k < +4$  (74).

|| Constantan = 54% Cu, 43.6% Ni, 1% Mn, 1.4% Fe.

¶ Annealed ingot iron.

\*\* For 20 to 80° (3, 36, 74); for 0 to 100° (78); for others (74).

†† For some samples  $\mathcal{E}_0 > 0$ , for other  $\mathcal{E}_0 < 0$ ; maximum value observed was  $\mathcal{E}_0 = 1.33 \times 10^{-8}$  volt.

‡‡ Error in  $\mathcal{E}_0 = \pm 0.1 \times 10^{-8}$  volt.

§§ Heraeus' pure Pt; error in  $\mathcal{E}_0 = \pm 0.1 \times 10^{-8}$  volt. Source of specimen for  $\mathcal{Q}_0$  is not stated.

||| Baker's commercial.



TABLE 8.—EFFECT OF STRESS UPON THERMOELECTRIC PROPERTIES OF AL, FE, AND SN (17)

For explanation of symbols, see Table 7. Unit of  $E_o = 1\mu\text{v} = 10^{-6}$  volt; of  $p = 1 \text{ kg/cm}^2 = 14.22 \text{ lb./in.}^2 = 0.968 \text{ A}_m$ ;  $t =$  centigrade temperature,  $^{\circ}\text{C}$ .

$p$	2 000	4 000	6 000	8 000	10 000	12 000
$t$	1000 $E_o/t$ , "Pure" Al					
10	-3.1	-4.8	-6.8	-7.0	-7.6	-6.9
20	-2.7	-4.05	-4.9	-4.9	-4.75	-3.4
30	-2.27	-3.33	-3.8	-2.97	-1.87	+0.1
40	-1.82	-2.60	-2.58	-1.15	+0.75	+3.25
50	-1.40	-1.82	-1.26	+0.64	+3.16	+6.24
60	-0.97	-1.00	+0.08	+2.43	+5.47	+9.05
70	-0.50	-0.11	+1.47	+4.23	+7.69	+11.7
80	-0.025	+0.82	+2.89	+5.98	+9.82	+14.39
90	+0.48	+1.84	+4.32	+7.66	+11.89	+17.01
100	+1.01	+2.94	+5.77	+9.29	+13.84	+19.62

If  $p < 6500$ ,  $E_o(10)^{\circ} =$

$$[-2.167p + 0.131(10)^{-3}p^2]t + [24.5(10)^{-3}p - 0.2(10)^{-6}p^2]t^2.$$

If  $p > 6500$ ,  $E_o(10)^{\circ} = [-11.09(10)^3 + 0.497p - 14(10)^{-6}p^2] + [144.6 - 9.85(10)^{-3}p + 1.675(10)^{-6}p^2]t^2$ . Mean probable error in  $E_o$  is  $\pm 10^{-8}$  volt =  $0.01\mu\text{v}$ .

$t$	1000 $E_o/t$ , Commercial Al					
10	-1.2	-1.9	-1.7	-2.0	-0.6	+1.8
20	-0.95	-1.4	-0.95	0.0	+2.5	+5.8
30	-0.77	-0.90	-0.07	+1.9	+5.13	+8.83
40	-0.48	-0.25	+1.00	+3.70	+7.32	+11.60
50	-0.16	+0.52	+2.34	+5.40	+9.60	+14.40
60	+0.18	+1.40	+3.78	+7.33	+12.12	+17.50
70	+0.57	+2.31	+5.33	+9.57	+14.79	+21.04
80	+1.00	+3.25	+6.87	+11.80	+17.25	+24.70

Mean probable error in  $E_o = \pm 10^{-8}$  volt =  $0.01\mu\text{v}$ .

$t$	1000 $E_o/t$ , Fe, Ingot, An.*					
20	-4	-7.5	-14	-25	-37	-49.5
40	+4.2	+5.5	+5.5	+0.5	-3.2	-10.2
60	+11.0	+18.0	+21.2	+21.8	+24.2	+23.3
80	+15.1	+28.5	+39.4	+48.9	+56.0	+61.1
100	+16.7	+32.5	+46.0	+58.2	+68.6	+76.8

$t$	1000 $E_o/t$ , Fe, Ingot, Hd.*					
20	+1	-7.5	-12	-22.5	-27	-37
40	+5.8	+4.5	+5.2	-0.5	+2.5	+0.2
60	+10.3	+17.3	+23.8	+25.7	+30.8	+36.7
80	+15.9	+30.2	+42.5	+52.5	+63.9	+76.5
100	+23.0	+44.2	+66.9	+87.0	+107.0	+128.0

$t$	1000 $E_o/t$ , Fe, Soft*					
20	-1.5	-5.5	-14.5	-25	-37.5	-56
40	+3.8	+5.5	+1.8	-3.8	-10.0	-20.5
60	+7.7	+13.7	+15.5	+14.7	+12.5	+7.3
80	+12.7	+23.1	+30.9	+36.8	+39.8	+39.9
100	+23.4	+42.0	+56.8	+69.4	+82.5	+95.6

\* An. = Pure American ingot iron, annealed; Hd. = same as An., but hard-drawn; soft = commercial soft iron wire. Mean probable error in  $E_o$  is  $\pm 5 \times 10^{-7}$  volt =  $0.5\mu\text{v}$ .

$t$	1000 $E_o/t$ , Sn					
10	+0.1	-0.4	-1.4	-4.1	-8.3	-13.6
20	+0.15	0.0	-0.5	-2.25	-5.15	-9.1
30	+0.40	+0.40	+0.37	-0.67	-2.50	-5.13
40	+0.60	+0.82	+1.05	+0.52	-0.48	-2.02
50	+0.76	+1.16	+1.56	+1.40	+0.96	+0.20
60	+0.87	+1.38	+1.85	+2.03	+1.95	+1.72

TABLE 8.—(Continued)

$p$	2 000	4 000	6 000	8 000	10 000	12 000
$t$	1000 $E_o/t$ , Sn					
70	+0.91	+1.52	+2.09	+2.46	+2.61	+2.73
80	+0.92	+1.59	+2.20	+2.72	+3.04	+3.36
90	+0.91	+1.63	+2.29	+2.87	+3.29	+3.72
100	+0.87	+1.65	+2.32	+2.92	+3.41	+3.90

Mean probable error in  $E_o$  is  $\pm 2 \times 10^{-8}$  volt =  $0.02\mu\text{v}$ .

TABLE 9.—EFFECT OF LONGITUDINAL MAGNETIC FIELD ( $H$ ) AND OF TENSION ( $\tau$ ) UPON THERMOELECTRIC PROPERTIES OF METALS (12)

$\tau_H E_o$  = thermo emf around a circuit composed of two specimens of the same material, one specimen ( $\tau H$ ) is subjected to tension  $\tau$  and field  $H$ ; for the other specimen ( $o$ ),  $\tau = 0$ ,  $H = 0$ ; one junction is at  $t_1, ^{\circ}\text{C}$  and the other at  $t_2, ^{\circ}\text{C}$ .  $\tau_H Q'_o = \tau_H E_o / (t_2 - t_1)$ . In certain cases,  $\tau_H Q'_o = a(1 - e^{-0.001bH})$  if  $\tau$ ,  $t_1$  and  $t_2$  are kept constant.  $H_m$  is value of  $H$  at which  $\tau_H Q'_o$  is a maximum.

In general, the algebraic value of  $HQ'_o$  decreases as the hardness, the intensity of magnetization, and  $(t_2 - t_1)$  increase, either individually or collectively.

For the following data,  $t_1 = 14^{\circ}\text{C}$ ,  $t_2 = 100^{\circ}\text{C}$ ; probable error in  $Q' = \text{ca. } 0.5 \times 10^{-6}$  volt/ $^{\circ}\text{C}$ . Unit of  $Q'$  and  $a = 1\mu\text{v}/^{\circ}\text{C} = 10^{-6}$  volt/ $^{\circ}\text{C}$ ; of  $H = 1$  gauss; of  $\tau = 1 \text{ kg/cm}^2 = 14.22 \text{ lb./in.}^2$ ; of  $b = 1 \text{ gauss}^{-1}$ .

Metal	$H$	$\tau$	$\tau_H Q'_o$				$\tau_H Q'_o$	$H_m$	$a$	$b$
			400	450	800	$\infty$				
Co*	0	+90	+91	+96	+97				+97	-6.4
Co†	0	+60	+64	+81	+93				+93	-2.6
Fe†	0	+80		+53	+44	+110	100			
	1620		0	-28	-40	+35	40			
Fe, C‡	0	+50			+35	+68	200			
Ni	0	+329	+336	+353	+355				+355	-6.5
	447	+382	+386	+390	+392				+392	-9.2
	970	+408	+424	+480	+485				+485	-4.6

\* Cast. † Rolled. ‡ Pure Fe.  $Q'$  rises rapidly to a maximum, and then decreases. If  $H > 200$ ,  $HQ'_o$  for annealed Fe is  $40 \times 10^{-6}$  volt/ $^{\circ}\text{C}$  less than  $HQ'_o$  for unannealed iron. For soft Fe,  $HQ'_o > 0$ ; for annealed steel,  $HQ'_o < 0$ . § Hard steel. || Annealed.

TABLE 10.—EFFECT OF MAGNETIC FIELD ( $H$ ) AND TENSION ( $\tau$ ) UPON THERMO EMF OF BIMETALLIC CIRCUITS (75)

$\Delta E/E = (ME'_{Cu} - ME'_{Cu}) / ME'_{Cu}$ , where  $ME'_{Cu}$  = thermo emf of the  $M$ -Cu circuit when  $M$  is subjected to  $H$  and  $\tau$ ,  $ME'_{Cu}$  = thermo emf of the same circuit when  $H = 0$ ,  $\tau = 0$ ; the temperatures ( $t_1$ ,  $t_2$ ) of the junctions are the same for  $ME'_{Cu}$  as for  $ME'_{Cu}$ . Probable error in  $\Delta E/E = \text{ca. } 2\%$  of  $\Delta E/E$ . The composition of each metal  $M$  is stated in the table.  $H_m$  = value of  $H$  at which  $\Delta E/E$  is a maximum. Unit of  $H = 1$  gauss; of  $\tau = 1 \text{ kg/cm}^2 = 14.22 \text{ lb./in.}^2$ ; of composition of  $M = 1 \text{ wt. } \%$ .

A. Longitudinal magnetic field;  $t_1 = 0^{\circ}\text{C}$ ,  $t_2 = 100^{\circ}\text{C}$

A. Longitudinal magnetic field, $H = 0, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100$ gauss								
$M$		$H$	200	400	800	$\infty$	Maximum, $\Delta E/E$	$H_m$
Fe	Cu	$\tau$	1000 $\Delta E/E$					
100	0	0	+14.1	+10.8	+7.6	+6.0	+15.3	100
		516	+8.7	+5.25	+2.1	+0.5	+10.3	90
		1050	+2.85	-0.75	-3.9	-6.0	+4.7	90
		2090	-4.65	-7.95	-11.4	-13.6	-13.6	$\infty$
99.2	0.8	0	+18.6	+15.75	+12.9	+10.5	+19.2	150
		741	+13.35	+10.35	+7.3	+5.0	+14.7	110
		935	+8.85	+5.85	+2.48	+0.5	+10.5	100
		1860	+3.0	0.0	-3.75	-6.5	+4.6	60
98.5	1.5	0	+52.5	+43.5	+34.0	+27.0	+56.0	100
		1020	+31.5	+21.0	+10.5	+2.0	+36.0	100
		2040	+11.0	+0.5	-11.0	-20.0	+17.0	75



TABLE 10A.—(Continued)

<i>M</i>		<i>H</i>	200	400	800	∞	Maximum, $\Delta E/E$	<i>H<sub>m</sub></i>
Fe	Cu	$\tau$	1000 $\Delta E/E$					
98.0	2.0	0	+38.5	+32.5	+25.0	+21.0	+40.0	120
		1190	+25.5	+18.5	+11.0	+4.0	+28.5	100
		2370	+11.3	+4.0	-5.8	-10.5	+15.3	75
96	4	0	+28.8	+25.0	+20.5	+17.0	+29.5	120
		1100	+21.5	+17.0	+11.8	+7.5	+22.5	110
		2200	+13.3	+8.5	+3.0	-1.0	+14.9	100
94	6	0	+26.0	+21.0	+15.6	+12.0	+29.0	100
		930	+14.0	+8.0	+2.5	-1.5	+18.0	80
		1850	+5.5	-0.5	-7.5	-13.5	+10.0	70
93	7	0	+44.5	+34.5	+25.5	+18.5	+49.3	95
		1160	+24.0	+13.0	+2.8	-6.0	+31.0	90
		2310	+3.0	-8.5	-20.0	-29.0	+12.0	70
Fe	Ni							
98.9	1.1	0	+24.8	+19.3	+15.8	+12.1	+27.0	100
		964	+14.0	+8.5	+3.4	+0.5	+16.6	95
		1920	+4.5	-0.9	-6.5	-10.0	+7.0	80
98.1	1.9	0	+45.0	+37.5	+29.8	+25.0	+48.0	100
		984	+26.0	+17.7	+10.0	+5.0	+32.0	90
		1960	+9.5	+1.5	-7.0	-12.5	+14.0	70
93	7	0	+5.3	+5.05	+4.6	+4.1	+5.4	240
		963	+3.6	+3.2	+2.7	+2.1	+2.7	120
		1920	+1.95	+1.4	+0.95	+0.45	+2.25	100
88.7	11.3	0	+2.6	+3.2	+3.2	+2.9	+3.25	500
		931	+2.5	+2.8	+2.85	+2.5	+2.87	700
		1860	+2.1	+2.5	+2.45	+2.1	+2.5	430
0	100	0	+7.00	+8.70	+9.60	+9.75	+9.75	∞
		1290	+6.25	+10.50	+12.90	+13.30	+13.30	∞
		2610	+3.85	+9.00	+13.80	+14.75	+14.75	∞

B. Transverse magnetic field;  $t_1 = 22^\circ\text{C}$ ,  $t_2 = 100^\circ\text{C}$ 

$M$	$\tau = 0$		$\tau = 1370$		$\tau = 2070$	
Ni	$H$	$1000\Delta E/E^*$	$H$	$1000\Delta E/E^*$	$H$	$1000\Delta E/E^*$
100%	3000	+ 9.0	3100	+5.9	3100	+4.8
	5900	+12.5	5750	+8.6	5750	+5.7
	8500	+16.5	8400	+8.4	8400	+5.6

\* Change due to  $H$ ,  $\tau$  being constant.

TABLE 11.—PELTIER COEFFICIENT: DIRECTLY OBSERVED

For all couples including constantan, see Table 12

When  $MP_R$  is positive, there is an absorption of heat as the current passes from  $R$  to  $M$ . When  $M$  is a binary alloy, the % by weight of the second component appears under the symbol of that component. The coefficients for other couples can be computed from data in Tables 1 to 6; the accuracy of values so computed probably exceeds that of those directly measured. Unit of  $P = 1\mu\text{v} = 10^{-6}$  volt; of "Error" = 1% of  $P$ ;  $t$  = centigrade temperature,  $^\circ\text{C}$ .

<i>M</i>	<i>R</i>	<i>t</i>	$MP_R$	Error	Lit.
Ag.....	Cu	0	+ 480	2	(50)
	Cu	0	- 68	2	(14)
	Cu	18	- 30	30	(24)
Ag.....	Pd			2	(14)
	0	Cu	0	- 68	
	10		0	- 1 593	
	20		0	- 2 215	
	30		0	- 3 240	
	40		0	- 4 960	
	50		0	- 8 650	
	60		0	- 9 980	
	70		0	- 8 500	
	80		0	- 6 150	
	90		0	- 4 290	
	100		0	- 2 380	

TABLE 11.—(Continued)

<i>M</i>	<i>R</i>	<i>t</i>	$MP_R$	Error	Lit.
Ag.....	Sn				
	70	Cu	20	- 674	2 (14)
Al.....		Cu	15.8	- 695	1.5 (24)
Au.....		Cu	0	- 329	2 (14)
Au.....	Pd				
	0	Cu	0	- 329	2 (14)
	10		0	- 2 086	
	20		0	- 2 865	
	30		0	- 7 710	
	40		0	- 10 610	
	50		0	- 8 200	
	60		0	- 6 720	
	70		0	- 6 210	
	80		0	- 5 870	
	90		0	- 4 810	
	100		0	- 2 380	
Bi $\perp$ .....		Cu	8.1	- 14 620	2-3 (51)
			20.6	- 15 730	2-3 (51)
			22.4	- 15 700	2-3 (51)
			19.75	- 14 120	2 (16)
Bi $\parallel$ .....		Cu	20.5	- 21 060	2 (16)
Bi(45)*.....		Cu	19.5	- 23 300	2 (16)
Bi $\uparrow$ .....		Cu	18	- 16 130	1 (24)
		Cu	20.7	- 19 350	2 (24)
		Cu	25	- 22 300	4 (57)
Bi.....	Sn				
	3.75	Cu	20.7	+ 10 870	2 (24)
	6.36		20.7	+ 11 670	2 (24)
	9.93		20.7	+ 10 450	2 (24)
C.....		Cu	20(?)	- 2 943	3 (40)
Cd $\uparrow$ .....		Cu	0	+ 682	2 (7, 25, 50, 57)
Cu.....	See other metal in column <i>M</i>				
Cu Ni	See Table 12				
Constantan					
Cu, Ni, Zn $\ddagger$ .....		Cu	20	- 7 400	2 (14)
Fe.....		Cu	0	+ 3 680	3 (50)
		Cu	19	+ 2 893	3 (40)
		Cu	20	+ 2 995	2 (14)
		Cu	25	+ 2 930	4 (57)
		Hg $\uparrow$	18.5	+ 4 880	2 (63)
		Ni	15	+ 9 600	(7)
German silver, see Cu, Ni, Zn					
MoS $_2$ .....		Cu	23.5	- 173 500	20 (40)
Ni $\uparrow$ .....		Cu	0	- 5 070	2 (4, 7, 24, 25, 50)
Nickelini $\P$ .....		Cu	20	- 5 540	2 (14)
Pd.....		Cu	0	- 2 380	2 (14)
		Cu	0	- 2 920	2 (14)
Pd.....	Pt				
	0	Cu	0	- 2 920**	2 (14)
	10		0	- 738	
	20		0	+ 51	
	30		0	+ 284	
			20	- 296	
	40		0	+ 170	
			20	- 188	
	50		0	- 79	
	60		0	- 250	
	70		0	- 545	
	80		0	- 748	
	90		0	- 1 134	
	100		0	- 1 531	
Pt.....		Cu	0	- 1 531	2 (14)
		Cu	0	- 370	3 (50)
		Cu	17.1	- 845	1.3 (24)
		Cu	20	- 1 070	2 (14)
		Cu	25	+ 5 640	4 (57)
		Cu	19	+ 175 100	15 (40)
Zn $\uparrow$ .....		Cu	0	+ 684	3 (7, 50, 57)

\* Bi $\perp$ , Bi $\parallel$ , Bi $_{45}$  = current perpendicular, parallel, at  $45^\circ$  to axis of Bi crystal. See also Table 13. For transverse Peltier effect, see p. 214.

$\uparrow$  Direction of current with reference to axis of crystal is not stated.

$\ddagger$  See Table 12.

$\P$  German silver, composition is not stated, it usually lies between 50Cu, 30Ni, 20Zn and 57Cu, 7Ni, 36Zn.

$\P$  Composition is not stated; probably 75 to 55 Cu; 18 to 32 Ni; 0 to 20 Zn.

\*\* Compare with corresponding value for Ag-Pd, Au-Pd by same author.



TABLE 12.—PELTIER COEFFICIENT: DIRECTLY OBSERVED  
VARIATION WITH TEMPERATURE

Data for other couples may be derived from data in Tables 1 to 6; values so computed are probably more accurate than those directly measured.  $MP_R = u + vt + wt^2$  if  $t$  lies between  $t_1$  and  $t_2$ . Unit of  $P = 1\mu\text{V} = 10^{-6}$  volt; of "Error" = 1% of  $P$ ;  $t_1, t_2$  = centigrade temperature, °C.

M	R	$t_1$	$t_2$	u	v	w	Error	Lit.
Cd	Cu	0	25	+ 682	- 7.6		2	(7, 25, 50, 57)
Constantan* (Cu, Ni)	Cd	21	570	- 8 710	-41.0	-0.020	2	(25)
	Cu	0	20	-11 340	-61.0		1	(14, 16)
	Cu	15.5	15.5	-10 210				(7)
	Fe	0	560	-12 980	-44.0	-0.051		(7, 25)
	Hg	-80.6	+20	- 8 250	-62.3	-0.32		(25)
	Pb	20	440	- 7 970	-35.1		2	(25)
	Sn	20	570	- 7 710	-34.2	-0.012	2	(25)
Cu (see other metal in column M)								
Fe	Hg	18.5	182	+ 4 600	+15.6	-0.034	2	(53)
Ni	Cu	0	445	- 5 070	-23.0	-1.24	2	(4, 7, 24, 25, 50)
Zn	Cu	0	25	+ 684	- 9.2		3	(7, 50, 57)

\* Composition is not stated; probably about 60Cu, 40Ni.

TABLE 13.—PELTIER COEFFICIENT OF BISMUTH: DIRECTLY OBSERVED EFFECT OF MAGNETIC FIELD (16)

$\Delta P = P' - P$ ,  $P'$  = Peltier coefficient when  $H = 2300$  gauss,  $P$  = Peltier coefficient when  $H = 0$ ; the direction of the current ( $\parallel$ ,  $\perp$ ,  $45^\circ$ ) is referred to the crystallographic  $c$ -axis. AB denotes the plane which includes the axis and the direction of the current. Unit of  $\Delta P = 1\mu\text{V} = 10^{-6}$  volt.

Direction of current	$\perp$	$\parallel$	$45^\circ$
Direction of H	$\Delta P$		
$\perp$ AB	-565	-1393	-2560
$\parallel$ AB, $\parallel$ axis	-416	- 226	- 125
$\parallel$ AB, $\perp$ axis	-264	-1393	-1286
$\parallel$ AB, $\parallel$ current	-264	- 226	- 753
$\parallel$ AB, $\perp$ current	-416	-1393	- 991

TABLE 14.—THOMSON COEFFICIENT ( $\sigma$ ): DIRECTLY OBSERVED

$\sigma = \alpha + \beta t(10)^{-2} + \gamma t^2(10)^{-5}$  if  $t$  lies between  $t_1$  and  $t_2$ ; when  $\sigma$  is positive, there is an absorption of heat as current flows from regions of higher to those of lower temperature.

For other cases,  $\sigma$  may be computed by means of the relation  $\sigma_M - \sigma_R = -T(\partial^2 M E_R / \partial t^2)$ , using the data in Tables 1 to 6; probably values so computed are more accurate than those directly measured. Unit of  $\sigma = 1\mu\text{V}/^\circ\text{C} = 10^{-6}$  volt/°C; of "Error" = 1% of  $\sigma$ ;  $t_1, t_2$  = centigrade temperature, °C.

## A. Elementary substances

Symbol	$t_1$	$t_2$	$\alpha$	$\beta$	$\gamma$	Error	Lit.
Ag	- 168	- 123	- 0.112	+ 9.47	+42	2	(15)
	- 123	+ 127	- 1.17	- 0.50		2	(15)
	+ 123	+ 525	- 3.08	- 0.302		2	(55)
Al	- 13	+ 119	- 0.04	+ 0.475		10	(15)
	+ 71	+ 322	+ 0.2685	+ 0.080		2	(25)
Au	- 173	- 100	- 1.01	+ 0.65	+ 6.1	5	(15)
	- 100	+ 103	- 1.49	- 0.44		5	(15)
Bi*	+ 25	+ 32.5	+ 6.76	+ 2.8		1.5	(54)
	+ 43.5	+ 43.5	+ 58			10	(24)
			+ 5.32			4	(6)
			+ 4.27				(67)
C(v)†			- 4.6				(52)
C(v)†	+1527	+1827	+ 3.7	+ 0.01		5	(51)
Cd	- 163	- 83	- 2.25	- 1.5		5	(15)
	- 83	+ 107	- 5.62	- 5.99	+18.6	5	(15)
	+ 48	+ 343	- 9.00	- 1.55	- 1.5	2	(25)
Cu	- 172	- 60	- 2.244	- 2.5	- 6.4	5	(14, 15)
	- 60	+ 127	- 1.42	- 0.74		5	(15)
	- 96.7	+ 107	- 1.50	- 0.48		2	(9)
	+ 252	+ 678	- 1.37	- 0.235		2	(55)

TABLE 14A.—(Continued)

Symbol	$t_1$	$t_2$	$\alpha$	$\beta$	$\gamma$	Error	Lit.
Fe†	- 51	+ 115	+ 4.00	+ 8.4		5	(9)
	+ 32	+ 182	+ 7.66	+ 4.1	+17	3	(43)
	+ 53	+ 308	+ 2.97	+ 1.85		4	(6)
	+ 48	+ 48	+ 11.3			1	(52)
	+ 49	+ 148	- 16.4	+20.8		7	(1)
	+ 91	+ 441	+ 7.785	+ 8.61	-21.4	5	(55)
Hg	+ 50	+ 150	+ 5.065	+ 3.35	+ 1.7	5	(70)
	+ 47	+ 262	+ 1.20	+ 1.58	- 4.8	2	(25, 42)
Pb	- 153	+ 117	+ 0.61	+ 0.221	- 0.38	3	(15)
	+ 45	+ 342	+ 0.03	- 0.47	+ 0.55	2	(25)
Pt	- 72	+ 128	+ 9.10	- 0.475	+ 4.75	1	(9)
Si	+ 46	+ 46	+794			10	(52)
Sn	- 171	+ 112	- 0.09	+ 0.50		5	(15)
	+ 51	+ 266	+ 0.35	+ 0.093		1	(25)
Ta	+1427	+1827	+ 12.5	- 2.0		5	(51)
W	+1227	+1927	- 32.4	+ 3.5		5	(51)
	+1527	+2127	- 12.54	+ 2.0		2	(26)
Zn†	- 173	+ 40	- 2.74	- 1.15		3	(15)
	+ 40	+ 343	- 3.112	- 0.235		2	(25)

## B. Alloys and compounds

Alloy	$t_1$	$t_2$	$\alpha$	$\beta$	$\gamma$	Error	Lit.
Bi-Sn‡							
1.23	+48	+ 76	+ 62.4	+111		1.5	(54)
3.01	+30	+ 72	+ 65.0	+120		1.5	(54)
10.0	+38	+ 75	+ 75.8	+ 39		1.5	(54)
23.6	+25	+ 68	+ 33.3	+ 12		1.5	(54)
1.00	+43.5	+ 43.5	+676			10	(24)
2.00	+43.5	+ 43.5	+537			10	(24)
3.72	+43.5	+ 43.5	+207			10	(24)
6.36	+43.5	+ 43.5	+137			10	(24)
MoS₂¶	+50	+ 50	-113			20	(52)
Constantan**	+87	+481	+ 20.00	+ 2.554	-10.05	10	(55)
	+60	+ 60	+ 19.78			5	(55)
	+20.5	+ 20.5	+ 25.33			5	(14)
German silver**	+23	+ 23	+ 10.45			5	(14)
Manganin**	+60	+ 60	- 2.85			5	(55)
Nickelin**	+31	+ 31	+ 17.14			5	(14)
Piano wire**	+28	+ 28	+ 7.7			5	(14)

\*  $\sigma$  varies greatly from one specimen to another. See also Table 1.

† C(v) = 70% graphite; C(v) = lamp filament.

‡ Exhibits thermoelectric hysteresis, sometimes as great as 25% of mean.

The occurrence of signs opposite to those which would be inferred from  $E$  is probably due to the presence of impurities.

§ Numerical value of  $\sigma$  increases rapidly between 40 and 100°C.

¶  $\sigma$  varies from one specimen to another; the % of Sn by weight is indicated below the Sn.

¶ The current flows perpendicular to  $c$ -axis of the crystal.

\*\* Composition is not stated. Possibly: Constantan = 60Cu, 40Ni. German silver between 50Cu, 30Ni, 20Zn and 57Cu, 7Ni, 36Zn. Manganin = 84Cu, 12Mn, 4Ni. Nickelin = 75 to 55Cu, 18 to 32Ni, 0 to 20Zn. Piano wire = 98.89Fe, 0.57C, 0.09Si, 0.01S, 0.02P, 0.42Mn.

## LITERATURE

(For a key to the periodicals see end of volume)

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## ELECTRICAL CONDUCTIVITY OF AQUEOUS SOLUTIONS

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Introduction, symbols and units.	Introduction, symboles et unités.	Einleitung, Symbole und Einheiten.	Introduzione, simboli e unità.....	229
Standard solutions for determining cell constants.	Solutions étalons pour la détermination de la constante des cuves.	Normallösungen für die Bestimmung der Widerstands-Kapazität des Gefäßes.	Soluzioni campione per determinare le costanti delle cellule.....	230
Ionic conductivities.	Conductibilités ioniques.	Ionen-Leitfähigkeiten.	Conducibilità ionica....	230
Solutions of salts and of all inorganic strong electrolytes.	Solutions de sels et de tous les électrolytes forts inorganiques.	Salzlösungen und Lösungen aller starken anorganischen Elektrolyte.	Soluzioni di sali e di tutti gli elettroliti forti inorganici.....	230
Saturated solutions of slightly soluble strong electrolytes.	Solutions saturées des électrolytes forts peu solubles.	Gesättigte Lösungen wenig löslicher starker Elektrolyte.	Soluzioni sature di elettroliti forti debolmente solubili.....	256
Solutions of all weak electrolytes and of all organic acids and bases.	Solutions de tous les électrolytes faibles et de tous les acides et bases organiques.	Lösungen aller schwachen Elektrolyte und aller organischen Säuren und Basen.	Soluzioni di tutti gli elettroliti deboli e di tutti gli acidi e basi organici.....	259
Solutions containing two solutes.	Solutions contenant deux corps dissouts.	Lösungen mit zwei gelösten Stoffe.	Soluzioni contenenti due sostanze disciolte.....	305
Soap solutions, Vol. V, p. 458.	Solutions de savon, Vol. V, p. 458.	Seifenlösungen, Bd. V, S. 458.	Soluzioni di saponi, Vol. V, p. 458.	

## INTRODUCTION

ABBREVIATIONS, SYMBOLS AND UNITS	ABBREVIATIONS, SYMBOLES ET UNITÉS	ABKÜRZUNGEN, SYMBOLE UND EINHEITEN	ABBREVIAZIONI, SIMBOLI, E UNITÀ
$\kappa$ Specific conductance in ohm <sup>-1</sup> cm <sup>-1</sup>	$\kappa$ Conductibilité spécifique en ohm <sup>-1</sup> cm <sup>-1</sup> .	$\kappa$ Spezifische Leitfähigkeit in Ohm <sup>-1</sup> cm <sup>-1</sup> .	$\kappa$ Conduttura specifica in ohm <sup>-1</sup> cm <sup>-1</sup> .
$C$ Concentration in milliformula-weights per l of solution at the temperature $t$ , unless otherwise indicated.	$C$ Concentration en millimolécule grammes pour l de solution à la température $t$ , à moins d'une autre indication.	$C$ Konzentration in Milligrammformel-Gewicht für ein l der Lösung bei der Temperatur $t$ , wenn nichts anderes angegeben.	$C$ Concentrazione in milliformula-grammo per l di soluzione a temperatura $t$ , a meno che non venga altrimenti indicato.
$\Lambda = 10^3 \kappa / C$	$\Lambda = 10^3 \kappa / C$ .	$\Lambda = 10^3 \kappa / C$ .	$\Lambda = 10^3 \kappa / C$ .
The unit of specific conductance is the reciprocal ohm and it is assumed that the standardizing solutions shown in the tables below have the specific conductances there given. To bring the older data into harmony with these values, the authors' conductance values have been increased by the appropriate amount as indicated in column 5 of Table 1.	L'unité de conductibilité spécifique est l'ohm réciproque et il a été admis que les solutions étalons données dans les tables ci-dessous ont les conductibilités spécifiques mentionnées à cette place. Pour mettre en harmonie avec ces valeurs les données plus anciennes, les valeurs de conductibilité données par les auteurs ont été augmentées d'une quantité appropriée, comme cela est indiqué dans la colonne 5 de la Table 1.	Die Einheit der spezifischen Leitfähigkeit ist das reziproke Ohm. Es wird angenommen, dass die Lösungen, welche zur Bestimmung der Widerstands-Kapazität den Gefässen dienten, den spezifischen Leitfähigkeit haben, welcher in den unteren Tabellen angegeben ist. Um ältere Daten mit diesen in Übereinstimmung zu bringen, werden die Leitfähigkeitswerte der Autoren um einen entsprechenden Anteil erhöht, wie es in der Kolonne 5 der Tafel 1 angegeben ist.	L'unità della conducibilità specifica è il reciproco dell'ohm; si suppone inoltre che le soluzioni titolate di confronto che figurano nelle tabelle più sotto hanno la conducibilità specifica ivi indicata. Per poter mettere d'accordo con questi i valori più vecchi, i valori dagli autori sono stati accresciuti nel rapporto dovuto, come è indicato nella colonna 5 della Tabella 1.



# SOLUTIONS FOR DETERMINING CELL CONSTANTS (199)

TABLE 1.—KOHRAUSCH SOLUTIONS

The values given below have the following significance: Col. 2, grams of KCl per 1000 g H<sub>2</sub>O, weights in air ( $d = 0.0012$ ). Col. 3, temperature of measurement. Col. 4, specific conductance  $\text{ohm}^{-1} \text{cm}^{-1}$ . Col. 5, % difference, Col. 4 value minus the older Kohlrausch value.

1	2	3	4	5
Solution number	$\frac{\text{g KCl}}{\text{kg H}_2\text{O}}$	$t, ^\circ\text{C}$	$\kappa$ (I. C. T. value)	Corr., %
1	76.9153	0	0.6531	0.150
		18	.098116	.108
		25	.111687	.101
2	7.49313	0	.0071416	.118
		18	.0111846	.048
		25	.0128765	.027
3	0.74756	0	.0077422	.229
		18	.00122238	.214
		25	.00141037	.186
4	76.925	18	.098128	.145
5	7.4945	18	.0111871	.145
6	0.74766	18	.00122252	.145
7	Max. H <sub>2</sub> SO <sub>4</sub>	25	0.8242	0.18

TABLE 2.—PARKER SOLUTIONS

$$\kappa = A + 10^{-3}Bt + 10^{-6}Ct^2$$

$\frac{\text{g KCl}}{\text{kg H}_2\text{O}}$	76.6276	7.47896	0.746253
$d, \text{g/cm}^3, 0^\circ\text{C}$	1.04804	1.004887	1.000372
$t, ^\circ\text{C}$	Values of $\kappa, \text{ohm}^{-1} \text{cm}^{-1}$		
0	0.065098	0.0071295	0.00077284
5	.073876	.0082055	.00089203
10	.082886	.0093158	.00101513
15	.092132	.0104603	.00114215
18	.097790	.0111636	.00122023

TABLE 2.—(Continued)

$\frac{\text{g KCl}}{\text{kg H}_2\text{O}}$	76.6276	7.47896	0.746253
$d, \text{g/cm}^3, 0^\circ\text{C}$	1.04804	1.004887	1.000372
$t, ^\circ\text{C}$	Values of $\kappa, \text{ohm}^{-1} \text{cm}^{-1}$		
20	0.101607	0.0116393	0.00127307
25	.111322	.0128524	.00140786
30	.121267	.0140996	.00154661
A =	0.065098	0.0071295	0.00077284
B =	1.7319	2.1178	2.3448
C =	4.681	6.850	7.816

\* In air ( $d = 0.0012$ ), brass weights.

## IONIC CONDUCTIVITY

TABLE 3.—ION CONDUCTANCES AT 18°C

Based upon I. C. T. atomic weights (*v.* Vol. I, p. 43) and upon the I. C. T. cell-constant values (Table 1 *supra*). Ion conductances not given here may be obtained by subtracting  $\Lambda_B$  (resp.  $\Lambda_{OH}$ ) from the  $\Lambda_0$  values given in the tables beginning on p. 259.

Ion	$\Lambda$	$\frac{1}{\Lambda} \left( \frac{d\Lambda}{dt} \right)_{18}$	Ion	$\Lambda$	$\frac{1}{\Lambda} \left( \frac{d\Lambda}{dt} \right)_{18}$
H.....	315.2	0.01573	OH.....	173.8	0.018
Cs.....	67.46	.0212	Cl.....	65.24	.0216
K.....	64.20	.0217	Br.....	67.31	.0215
NH <sub>4</sub> .....	64.3	.0222	I.....	66.25	.0213
Na.....	43.16	.0244	NO <sub>2</sub> .....	61.62	.0205
Li.....	33.02	.0265	ClO <sub>3</sub> .....	54.87	.0215
Tl.....	65.3	.0215	BrO <sub>3</sub> .....	47.6	
Ag.....	53.8	.0229	IO <sub>3</sub> .....	33.78	.0214
$\frac{1}{2}$ Ca.....	51	.0247	C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> .....	35	.0238
$\frac{1}{2}$ Mg.....	45	.0256	$\frac{1}{2}$ C <sub>2</sub> O <sub>4</sub> .....	61	.0231
$\frac{1}{2}$ Ba.....	55	.0239	$\frac{1}{2}$ SO <sub>4</sub> .....	68	.0227
$\frac{1}{2}$ Pb.....	61	.0240	$\frac{1}{2}$ CrO <sub>4</sub> .....	72	

## SOLUTIONS OF SALTS AND OF ALL INORGANIC STRONG ELECTROLYTES

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
PART I.—Neutral halides, nitrates and sulfates.	Sec. I.—Halogénures, nitrates et sulfates neutres.	Abschnitt I.—Neutrale Halogenide, Nitrate und Sulfate.	Serie I.—Alogenuri neutri, nitrati e solfati.....	230
PART II.—All other salts and strong electrolytes.	Sec. II.—Tous les autres sels et les électrolytes forts.	Abschnitt II.—Alle anderen Salze und starken Elektrolyte.	Serie II.—Tutti gli altri sali, e gli elettroliti forti.	241

## PART I. CONDUCTIVITY OF NEUTRAL HALIDES, NITRATES AND SULFATES

EDWARD W. WASHBURN AND ALFONS KLEMENC

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE
Table 1.—Values of $C$ up to 0.5.	Table 1.—Valeurs de $C$ jusqu'à 0,5.	Tabelle 1.—Werte von $C$ bis 0,5.	Tabella 1.—Valori di $C$ fino a 0,5.
Table 2.—Values of $C$ from 0.5 to 1000.	Table 2.—Valeurs de $C$ de 0,5 à 1000.	Tabelle 2.—Werte von $C$ von 0,5 bis zu 1000.	Tabella 2.—Valori di $C$ da 0,5 a 1000.
Table 3.—Values of $C$ above 1000.	Table 3.—Valeurs de $C$ au dessus de 1000.	Tabelle 3.—Werte von $C$ über 1000.	Tabella 3.—Valori di $C$ sopra 1000.
In each table the salts are grouped according to the anion in the order F, Cl, Br, I, SO <sub>4</sub> , NO <sub>3</sub> , and under a given anion the cations follow the standard arrangement. ( <i>v.</i> Vol. III, p. viii).	Dans chaque table les sels sont groupés en accord avec l'anion dans l'ordre F, Cl, Br, I, SO <sub>4</sub> , NO <sub>3</sub> , et sous un anion donné, les cations suivent l'arrangement type ( <i>v.</i> Vol. III, p. viii).	In jeder Tabelle sind die Salze in der Reihenfolge ihrer Anionen angeordnet; F, Cl, Br, I, SO <sub>4</sub> , NO <sub>3</sub> . Unter den gegebenen Anionen folgen die Kationen in der Standardanordnung ( <i>v.</i> Bd. III, S. viii).	In ciascuna tabella i sali sono raggruppati secondo l'anione nell'ordine F, Cl, Br, I, SO <sub>4</sub> , NO <sub>3</sub> , e per un dato anione i cationi seguono l'ordinamento tipo ( <i>v.</i> Vol. III, p. viii).



TABLE 1.—VALUES OF  $C$  UP TO 0.3  
For literature references, *v.* Table 2

<b>F</b>		<b>RbCl, 18°</b>		$\frac{1}{2}\text{CaSO}_4$	
$C$	$10^6\kappa/C$	$C$	$10^6\kappa/C$	$C$	$10^6\kappa/C$
<b>TiF, 18°</b>		<b>CsCl, 18°</b>		<b>18°</b>	
0.1	114.40	0.1	132.0	0.1	115.5
0.2	114.66	0.2	131.7	0.2	114.0
<b>NaF, 18°</b>		<b>Br</b>		<b>25°</b>	
0.1	89.10	<b>(CH<sub>3</sub>)<sub>4</sub>NBr, 25°</b>		0.1	136.5
0.2	88.81	0.01	124.263	0.2	133.1
<b>KF, 18°</b>		0.05	123.958	$\frac{1}{2}\text{Na}_2\text{SO}_4$ , 18°	
0.1	110.02	0.07	123.807	0.1	109.7
0.2	109.79	0.1	123.586	0.2	108.8
<b>Cl</b>		0.2	123.010	$\frac{1}{2}\text{K}_2\text{SO}_4$ , 18°	
<b>NH<sub>4</sub>Cl, 18°</b>		$\frac{1}{2}\text{RaBr}_2$ , 18°		0.1	130.5
0.1	129.3	0.1	123.9	0.2	129.8
0.2	128.9	0.2	122.9	<b>NO<sub>3</sub></b>	
<b>(C<sub>2</sub>H<sub>5</sub>)<sub>4</sub>NCl, 25°</b>		<b>KBr, 18°</b>		<b>NH<sub>4</sub>NO<sub>3</sub>, 18°</b>	
0.01	109.139	0.1	130.86	0.1	(125.9)
0.05	108.933	0.2	130.57	0.2	(125.8)
0.07	108.837	<b>I</b>		$\frac{1}{2}\text{Pb}(\text{NO}_3)_2$ , 18°	
0.1	108.692	<b>(C<sub>2</sub>H<sub>7</sub>)<sub>4</sub>NI, 25°</b>		0.1	120.59
0.2	108.281	$C$	$10^6\kappa/C$	0.2	119.80
$\frac{1}{3}\text{InCl}_3$ , 25°		0.01	99.649	<b>TiNO<sub>3</sub>, 18°</b>	
0.3	225	0.05	99.492	0.1	126.59
<b>TiCl, 18°</b>		0.07	99.378	0.2	126.26
0.1	130.15	0.1	99.307	<b>AgNO<sub>3</sub>, 18°</b>	
0.2	129.82	0.2	98.990	0.1	114.85
$\frac{1}{2}\text{CaCl}_2$ , 18°		<b>KI, 18°</b>		0.2	114.40
0.1	115.01	0.1	129.50	$\frac{1}{2}\text{Ca}(\text{NO}_3)_2$ , 18°	
0.2	114.39	0.2	129.24	0.1	111.75
$\frac{1}{2}\text{SrCl}_2$ , 18°		<b>SO<sub>4</sub></b>		0.2	111.03
0.1	(118.5)	$\frac{1}{2}(\text{NH}_4)_2\text{SO}_4$ , 18°		$\frac{1}{2}\text{Sr}(\text{NO}_3)_2$ , 18°	
0.2	(117.4)	0.1	130	0.1	111.58
<b>LiCl, 18°</b>		0.2	128	0.2	110.91
0.1	97.82	$\frac{1}{2}\text{ZnSO}_4$ , 18°		$\frac{1}{2}\text{Ba}(\text{NO}_3)_2$ , 18°	
0.2	97.53	0.1	109.6	0.1	115.16
<b>NaCl, 18°</b>		0.2	107.6	0.2	114.49
0.1	107.88	$\frac{1}{2}\text{CdSO}_4$ , 18°		<b>LiNO<sub>3</sub>, 18°</b>	
0.2	107.60	0.1	109.69	0.1	94.17
<b>KCl, 18°</b>		0.2	107.45	0.2	93.86
0.01	129.379	$\frac{1}{2}\text{CuSO}_4$ , 18°		<b>NaNO<sub>3</sub>, 18°</b>	
0.02	129.317	0.1	109.80	0.1	104.30
0.05	129.126	0.2	107.80	0.2	103.94
0.07	129.003	$\frac{1}{2}\text{MgSO}_4$ , 18°		<b>KNO<sub>3</sub></b>	
0.10	128.836	0.1	109.6	<b>18°</b>	
0.20	128.483	0.2	107.8	0.1	125.2
<b>100°</b>		<b>100°</b>		0.2	124.90
0.2	402.6	<b>0.2</b>		0.2	380.2

TABLE 2; see p. 232 to 238

TABLE 3.—VALUES OF  $C$  ABOVE 1000  
For literature references, *v.* Table 2

<b>F</b>		$\frac{1}{2}\text{ZnCl}_2$ —(Cont'd)		$\frac{1}{2}\text{MnCl}_2$ —(Cont'd)	
$C$	$10^6\kappa/C$	$C$	$10^6\kappa/C$	$C$	$10^6\kappa/C$
<b>NH<sub>4</sub>F, 18°</b>		<b>25°</b>		<b>25°</b>	
2 000	55.3	2 000	44.0	2 000	51.7
3 000	48.1	3 000	32.7	3 000	41.3
4 000	42.2	4 000	25.6	4 000	32.4
<b>TiF, 18°</b>		5 000	20.7	5 000	24.9
2 000	62.8	6 000	17.1	6 000	20.0
<b>AgF, 18°</b>		7 000	14.5	$\frac{1}{2}\text{FeCl}_2$ , 18°	
2 000	45.8	8 000	12.2	2 000	48.11
3 000	38.7	9 000	10.16	3 000	38.81
<b>KF, 18°</b>		10 000	8.40	4 000	30.84
2 000	66.2	12 000	5.72	5 000	24.05
3 000	58.9	14 000	3.85	6 000	18.13
4 000	52.7	16 000	2.48	$\frac{1}{3}\text{FeCl}_3$	
5 000	46.9	18 000	1.45	<b>0°</b>	
6 000	(42.0)	20 000	0.750	2 000	24.2
<b>RbF, 18°</b>		22 000	0.452	3 000	17.8
2 000	71.3	$\frac{1}{2}\text{CdCl}_2$		4 000	13.0
3 000	64.2	<b>18°</b>		<b>18°</b>	
4 000	57.5	2 000	14.17	2 000	37.5
<b>Cl</b>		3 000	10.02	3 000	27.8
<b>NH<sub>4</sub>Cl</b>		4 000	7.06	4 000	20.9
<b>0°</b>		5 000	4.85	5 000	15.90
2 000	63.0	6 500	3.33	6 000	12.40
3 000	62.0	7 760	2.27	8 000	6.20
4 000	(60.0)	9 180	1.45	$\frac{1}{2}\text{CoCl}_2$ , 18°	
<b>18°</b>		<b>25°</b>		2 000	49.2
2 000	92.2	2 000	16.06	3 000	39.7
3 000	88.3	3 000	11.42	4 000	32.1
4 000	85.1	4 000	8.26	7 650	11.7
5 000	80.7	5 000	5.74	$\frac{1}{2}\text{NiCl}_2$ , 18°	
<b>C<sub>2</sub>H<sub>5</sub>NH<sub>2</sub>HCl, 25°</b>		6 492	4.10	2 000	50.6
2 000	44.8	7 745	2.85	3 000	41.0
3 000	33.0	9 160	1.86	4 000	33.33
4 000	23.0	<b>100°</b>		$\frac{1}{3}\text{CrCl}_3$ , Violet, 18°	
$\frac{1}{4}\text{SnCl}_4$ , 18°		2 220	31.3	2 000	44.8
2 000	66.9	3 420	21.1	3 000	35.2
3 000	47.9	$\frac{1}{2}\text{CuCl}_2$		$\frac{1}{3}\text{AlCl}_3$	
4 000	32.7	<b>0°</b>		<b>0°</b>	
$\frac{1}{4}\text{ThCl}_4$ , 18°		2 000	28.9	2 000	27.3
2 000	44.33	3 000	22.4	3 000	21.5
3 000	36.3	4 000	16.8	4 000	16.4
4 000	29.81	<b>18°</b>		5 000	12.5
$\frac{1}{3}\text{InCl}_3$ , 25°		2 000	43.4	6 000	8.57
3 000	10.2	3 000	33.6	<b>18°</b>	
$\frac{1}{2}\text{ZnCl}_2$		4 000	26.0	2 000	44.5
<b>18°</b>		$\frac{1}{2}\text{MnCl}_2$		3 000	34.2
2 000	39.5	<b>18°</b>		4 000	27.16
3 000	29.6	2 000	45.3	$\frac{1}{2}\text{BeCl}_2$ , 18°	
4 000	22.9	3 000	35.7	2 000	41.4
5 000	18.4	4 000	28.17	3 000	34.4
6 000	15.2	5 000	21.8	4 000	29.0
7 000	12.9	6 000	16.30	$\frac{1}{2}\text{MgCl}_2$	
8 000	10.60	<b>0°</b>		<b>0°</b>	
11 520	5.36	2 000	33.0	2 000	33.0
15 370	2.36	3 000	27.7	3 000	27.7
		4 000	7.49	8 034	7.49

Continued on p. 239







TABLE 2.—(Continued)

[illegible]



TABLE 2.—(Continued)

TABLE 2.—(Continued)																
	°C	C = 0.5	1	3	5	10	20	30	50	70	100	300	500	700	1000	Lit.
KCl.....	0	80.0	79.7	79.2	78.4	77.284	75.6	73.2	72.25	71.295	69.4	66.9	66.0	65.098	(130, 131, 132, 199, 274)	
	18	127.86	127.07	126.05	124.15	122.18	119.72	115.51	113.7	111.79	107.74	102.25	100.3	98.08	(137, 199, 269)	
	25		147.4	146.3	143.8	141.180	138.04	133.1	131.03	128.620	123.9	117.2	114.6	111.861	(136, 156, 199)	
	50		226.0	224.0	219.1	215.1	210.1	201.5		194.3	187.9	173.3			(109, 192)	
	75					295.0				264.4					(180)	
	100	399.6	396.6	392.50	385.1	376.6	366.1	350.2	343.8	335.6	(341.1 at C = 80)					(150, 263)
	128					465.5				414.6					(180)	
	140									446					(180)	
	156									489					(180)	
	218														(180)	
	281														(180)	
	306														(51)	
1K <sub>2</sub> W <sub>2</sub> Cl <sub>2</sub> .....	1				77.1	73.4	68.9	62.6	60.1	57.4					79.3	(49)
RbCl.....	6														102.0	(49, 94, 95, 125, 126, 127, 128, 129, 132)
	18		130.1			125.2					114.8	81.6	106.2			(22, 28)
	25															(207)
	0		149.9	149.7	147.4	144.9	141	(139 at C = 30)			70.8	68.3	67.8	67.4		(93, 138, 185)
CaCl.....	18	131.05	130.35	129.20	127.15	124.89			115.5	113.28	108.6	102.7	100.8	98.8		(22, 28)
	25		152.0	150.3	147.7	145.0	141.3	(138.7 at C = 30)				(167)	162.2	156.4		(207)
	50															(109)
[Br]: NH <sub>4</sub> Br.....	0*			1.153	1.140	1.127	1.107	1.073	1.059	1.043	1.016	1.000	103.3	101.7		(82, 93)
	18	121.88	120.00					117.8	116.2	114.3	110.0	104.8				(11)
(CH <sub>3</sub> ) <sub>2</sub> NBr.....	25															(64, 66)
(C <sub>6</sub> H <sub>5</sub> CH <sub>2</sub> ) <sub>2</sub> NHBr.....	18				81.5	79.1	75.2									(66)
	25					(90.3 at C = 14.4)										(93, 95, 96, 97, 99)
1InBr <sub>3</sub> .....	18							(100.1 at C = 90)								(207)
1ZnBr <sub>2</sub> .....	25															(109)
1CdBr <sub>2</sub> .....	0															(34, 55, 273)
	18		64.0	59.3	52.3	46.5	40.3	32.4	29.8	27.1	21.8	15.2	22.0	18.8		(34, 55, 109, 273)
	25		103.7	97.0	85.9	75.8	65.7	52.4	47.9	43.2	35.1	25.2	25.4	21.7		(207)
	18		120	110.9	98.3	87.9	76.9	61.4	56.0	50.3	40.2	29.00				(85)
	25		187	173	153	135	117	94.5	86.8	77.6	62.0	43.6	37.6	31.7		(85)
1HgBr <sub>2</sub> .....	50															(85)
	18															(85)
1CuBr <sub>2</sub> .....	0															(109)
	25		68	66.8	64.2	62.3	60.2	56.7	55.4	53.9	50.2	44.6	42.5	40.0		(109)
	18		128	125	122	119	114	107	104	100	92	81	77	72		(109)
PtBr <sub>4</sub> .....	25															(171)
1MnBr <sub>2</sub> .....	18															(99)
1FeBr <sub>2</sub> .....	25															(3)
1CoBr <sub>2</sub> .....	0															(99)
	18		124.5	122.2	117.7	112.8	107.5									(109)
	25															(99)
1NiBr <sub>2</sub> .....	18															(109)
1CrBr <sub>3</sub> ; violet.....	50															(109)
1AlBr <sub>3</sub> .....	18															(109)
	25															(109)
1MgBr <sub>2</sub> .....	0															(109)
	18															(109)
	25															(109)
1CaBr <sub>2</sub> .....	50															(109)
1SrBr <sub>2</sub> .....	18															(109)
1BaBr <sub>2</sub> .....	0															(109)
	18															(109)
	25															(109)
1RaBr <sub>2</sub> .....	50															(109)
	18	121.1	119.6	117.2	113.5†	110.1	105.8	99.5†	169	164	153	91.2	87.3	83.1		(134)

\* Relative to As<sub>2</sub>Se<sub>3</sub> = 1. † For temp. coeff., see (134).



TABLE 2.—(Continued)

	°C	C = 0.5	1	2	5	10	20	50	70	100	300	500	700	1000	Lit.
LiBr.....	0		61.2	61.0	60.5	59.3	57.4	55.1	54.3	53.4	51.4	47.5	45.6	43.4	(109, 110)
	18							87.8	86.1	84.3	80.8	74.1	71.0	67.2	(93)
	18							99.0	97.6	95.9	91.7	84.5	81.7	78.0	(93)
NaBr.....	25	126.9	126.2	125.0	122.8	120.5	117.8	113.2	111.3	109.1	104.4	97			(109, 155, 195)
	50	1.0500	1.0452	1.0395	1.022	1.000	0.9697	0.9265	0.8880	0.8410	0.7570	(Relative to $\Lambda_{100} = 1$ )			(109)
	0								(74.7)	73.6	71.1	69.1	68.8	68.5	(245)
KBr.....	18	129.86	129.10	128.04	126.13	124.13	121.61	117.53	113.98	110.17	105.06	103.23	103.23	101.2	(43, 82, 93, 94, 136)
	25	150.8	149.9	148.5	146.1	143.5	140.5	135.7	133.6	131.4	127	123			(109, 156, 205)
	50	(234)	233.3	231.3	227.7	223.1	217.4	208.8	201.1	201.1	192.5	180.4	175.8	170.6	(82, 109)
RbBr.....	6									1.0860	1.0465	1.000			(95)
	18	(Relative to $\Lambda_{100} = 1$ )				1.476	1.424	1.345	1.309	1.265	1.161	1	104.2	101.7	(97)
	25	(Relative to $\Lambda_{100} = 1$ )									110.9	105.9	104.6	103.4	(93)
CaBr.....	18									114.9					(11)
(C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> NI.....	25	98.36	97.65	56.2		53.6	95.4	88.8	86.1	83.0	40.3				(109, 203)
	0		56.7	104.1	101.8	99.2	116	107	102	98					(109)
	25	106.7	105.4	126	124	121	107.1	98.7	95.2	91.2					(106)
(CH <sub>3</sub> ) <sub>4</sub> NI.....	35		123.5	121.2	116.8	112.4									(207)
(CH <sub>3</sub> ) <sub>4</sub> NI.....	25			(105 at C = 60)		37.5	30.9	22.7	20.2	17.7	13.8	87.5	83.6	78.6	(109)
†ZnI <sub>2</sub> .....	25		57.7	51.7	43.9							10.8			(35)
†CdI <sub>2</sub> .....	0														(84, 85, 273)
CdI <sub>2</sub> .....	18		98	91.2	76.6	64.7	53.3	39.3	34.5	29.7	23.5	18.3	16.8	15.32	(84, 85, 109, 273)
†CdI <sub>2</sub> .....	25		111	100.2	89.5	77.2	63.9	47.3	41.5	35.9	27.9	21.4	19.7	17.9	(109)
†CdI <sub>2</sub> .....	50		176	161	139	121	102	76	66.5	58.0	44.5	32.8			(109)
	100		(79 at C = 192) (42.2 at C = 959)												(92)
†MgI <sub>2</sub> .....	18							94.5	97.3	89.7	84.1	75.6	72.4	68.6	(93)
†CaI <sub>2</sub> .....	18							99.4	97.3	94.7	89.5	82.1	79.0	75.4	(93)
†SrI <sub>2</sub> .....	18							98.9	96.5	93.8	88.6	81.5	78.6	75.1	(93)
†BaI <sub>2</sub> .....	18							102.3	99.6	96.7	91.2	83.7	80.8	77.3	(93)
LiI.....	18							89.3	88.3	84.9	81.4	75.4	72.7	69.2	(93)
NaI.....	0		66.0	65.8	65.3	64.5	63.1	61.2	60.4	59.5	57.6	55.2	51.6	48.5	(109)
	18							97.6	96.0	94.2	90.1	84.0	81.6	78.5	(93)
	25		124.3	123.7	122.2	119.8	117.0	112.8	111.0	108.9	104.9	99.5	96.5	92.9	(109, 207)
	50		81.7	81.1	79.9	78.7	77.4	75.1	74.2	73.4	71.8	70.3	70.0	70.1	(109)
KI.....	0		127.99	126.96	125.07	123.19	120.83	117.01	115.42	113.78	110.42	106.07	104.72	103.39	(109, 112, 245)
	18	128.71													(49, 93, 135, 138, 185)
	25		147.3	146.3	144.3	141.9	139.1	134.4	132.5	130.5	126.5	120.5			(25, 109, 110, 203)
	50		230	226	217.7	213.0	209.1	202.0	198.6	194.8					(109)
	25		131	130	128	125.6	123.1	118.8	116.6	114.7					(25)
	25	113.0	112.0	110.9	108.6	106.4	103.7	99.7	(Corrected for solubility of I <sub>2</sub> )						(25); c.f. (35)
KI (estd. with I).....	18														(49)
KI.....	18														(49, 95)
RbI.....	6														(49)
	18														(94, 124, 202)
	30														(109, 134)
[SO <sub>4</sub> ]; (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> .....	18	127	124.5	122.0	117.9	113.5	(107.4)	(98.9)	(95.7)	92.0	(84.9)	75.5	71.9	68.2	(256)
	25		143.4	141.5	137.7	133.1	126.8	115.9	111.6	107.8	99.1	87.1	82.7	77.9	(234, 256)
ZrOSO <sub>4</sub> .....	18														(105, 185)
Zr(SO <sub>4</sub> ) <sub>2</sub> .....	25														(105, 185)
†Ti <sub>2</sub> SO <sub>4</sub> .....	0														(109, 116, 185)
†ZnSO <sub>4</sub> .....	18	63.6	60.3	56.4	50.4	45.4	39.7	33.4	31.4	29.4	25.5	20.9	18.9	16.3	(133, 135)
	25	103.4	98.5	92.1	81.8	72.8	63.8	52.8	49.1	45.4	39.1	31.4	28.7	26.0	(109, 135)
	50		112	106	95	84.3	73.4	60.6	56.5	52.4	44.8	36.3	33.3	30.0s	(109, 135)
†CdSO <sub>4</sub> .....	0	61.6	58.7	55.1	49.0	43.7	38.1	31.1	28.7	26.2	22.4	18.3	16.7	15.0	(109)
	18	102.79	97.58	90.79	79.59	70.23	60.87	49.53	45.91	42.15	35.84	28.70	26.75	23.56	(116, 185)
	25		113.2	105.5	93.0	81.7	70.4	57.0	52.9	49.0	(41.8)	33.3	30.5	27.3	(85, 133)
CuSO <sub>4</sub> .....	0	62.7	59.6	55.9	47.9	44.2	38.8	32.1	30.2	27.7	23.7	18.9	17.5	15.9	(85, 273)
	18	103.42	98.42	91.81	80.87	71.64	62.32	51.09	47.38	43.79	37.61	30.72	28.25	25.74	(109, 116, 274)



TABLE 2.—(Continued)

	°C	C = 0.5	1	2	5	10	20	50	70	100	300	500	700	1000	Lit.
$\dagger$ CuSO <sub>4</sub> —(Continued)	25	115.2	110.3	97.5	83.3	72.2	58.8	54.6	50.48	43.5	35.1	32.3	29.3	(89, 109, 135)	
$\dagger$ Ag <sub>2</sub> SO <sub>4</sub>	50	182	166	142	123.0	106.0	85.6	79.0	72.4	61.0	49.9			(109)	
	18	116.8	114.2	108.9	103.3	95.5								(85, 105)	
AgC <sub>2</sub> H <sub>3</sub> SO <sub>4</sub>	25	135.2	132.4	126.1	119.7	111.5								(105)	
$\dagger$ MnSO <sub>4</sub>	25	101.1	100.2	97.8										(153)	
	0		56.9	50.4	45.4	40.3	33.6	31.3	29.2	24.9	19.8			(109)	
$\dagger$ FeSO <sub>4</sub>	18													(124)	
	25		107	93.9	84.0	74.0	60.8	56.4	52.1	44.5	35.5	27.5	24.73	(109, 124)	
$\dagger$ Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	50					104	87.2	81.1	74.7	63.1	47.9	32.4	29.00	(109)	
	18													(124)	
	25													(124, 259)	
$\dagger$ Co <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	0													(109)	
	25													(124)	
	50													(109)	
$\dagger$ NiSO <sub>4</sub>	18													(109)	
	25													(124, 135, 202); cf.	
	50													(176.5)	
$\dagger$ Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> , violet	25													(109, 124); cf.	
	50													(176.5)	
UO <sub>2</sub> SO <sub>4</sub>	0													(109)	
VO <sub>2</sub> SO <sub>4</sub>	25													(109, 272)	
$\dagger$ Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(200, 261, 262)	
$\dagger$ Sc <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(92, 109)	
$\dagger$ Y <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(139)	
$\dagger$ La <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	0													(261)	
	25													(19)	
$\dagger$ Ce <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(19)	
$\dagger$ Pr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(186)	
$\dagger$ Nd <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(186)	
$\dagger$ Sm <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(186)	
$\dagger$ Gd <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(186)	
$\dagger$ Er <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(186)	
$\dagger$ Yb <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	25													(186)	
$\dagger$ MgSO <sub>4</sub>	18													(186)	
	0													(186)	
	18													(186)	
	25													(186)	
	50													(186)	
	100*													(186)	
	156†													(186)	
	217.8													(186)	
$\dagger$ CaSO <sub>4</sub>	18													(186)	
	25													(186)	
	50													(186)	
	100													(186)	
	156													(186)	
$\dagger$ Li <sub>2</sub> SO <sub>4</sub>	0													(186)	
	18													(186)	
	50													(186)	
	100													(186)	
	156													(186)	
$\dagger$ Na <sub>2</sub> SO <sub>4</sub>	0†													(186)	
	18													(186)	
	50													(186)	
	100													(186)	
	156													(186)	

\* 212.2 at C = 12.5, 178.8 at C = 25, 159.8 at C = 40, 135.9 at C = 80, 116.4 at C = 160.

† 224.7 at C = 12.5, 179.8 at C = 25, 157.8 at C = 40, 132.9 at C = 80, 112.7 at C = 160.

† Concentration in g./100 g. H<sub>2</sub>O.

\* 212.2 at C = 12.5, 178.8 at C = 25, 159.8 at C = 40, 135.9 at C = 80, 116.4 at C = 160.  
† 224.7 at C = 12.5, 179.8 at C = 25, 157.8 at C = 40, 132.9 at C = 80, 114.7 at C = 160.

† Concentrations are m (= millimole/kg H<sub>2</sub>O) and conductance data are 10<sup>4</sup>κ/m.



TABLE 2—(Continued)

	°C	C = 0.5	1	2	5	10	20	50	70	100	300	500	700	1000	Lit.
$\frac{1}{2}$ K <sub>2</sub> SO <sub>4</sub>	0	79.4	78.8	77.4	74.6	72.1	68.9	63.7	61.6	59.4	55.1	49.2	75.0	71.50	(60, 109, 116, 186)
	18	128.3	126.7	124.4	120.1	115.6	110.1	101.84	98.4	94.82	87.80	78.30			(124, 133, 136, 191, 241)
	25				139.6	134.2	127.9	117.98	114.10	109.71	101.26	90.3	(96.02 at C = 300)		(26, 37, 185)
	100					364.7		311.6		285.6	(319.6 at C = 40)				(191)
Rb <sub>2</sub> SO <sub>4</sub>	156					537						64.9	62.6	60.1	(191)
	217.8					672					95.9	85.8	82.1	78.2	(191)
[NO <sub>3</sub> ] NH <sub>4</sub> NO <sub>3</sub>	280.9					687					65.7	106.7	102.1	96.9	(191)
	305.7					637					101.5	62.1	60.6	59.0	(109, 245)
	6										116.9	94.4	91.7	88.6	(70, 126)
	18										174.7	108.0			(109)
	30										304	159.2	260	244	(109)
	100											273			(207)
C <sub>6</sub> H <sub>5</sub> N <sub>3</sub> O <sub>4</sub>	25										40.55	31.8	28.0	24.3	(217)
$\frac{1}{2}$ Pb(NO <sub>3</sub> ) <sub>2</sub>	0	117.94				64.71	60.42	53.27	50.28	47.04					(109, 212)
	18					103.44	96.89	86.28	82.05	77.18					(133, 184, 185)
	25					121.1	112.9	101.0	96.3	90.9					(72, 67, 184)
	50					184	173	155	148	139					(109)
	100					76.36	73.87	69.38	66.9	64.78					(114)
TiNO <sub>3</sub>	0	125.57				118.34	114.60	107.90	104.80	101.14					(138, 186)
	18					136.37	132.04	124.25	120.7	116.60					(114)
	25					59.8	57.9	54.5	52.8	51.2					(208)
	100										290	252	234	212	(109)
$\frac{1}{2}$ Zn(NO <sub>3</sub> ) <sub>2</sub>	0					110.8	115.9	98.9	95.7	92.1					(98)
	18					171	163	152	148	143					(109)
	25					96.2	91.9	85.5	82.7	79.7					(85, 273)
	50					110.8	106.5	99.3	96.8	92.9					(85, 273)
	100					61.0	58.5	54.8	53.4	51.7					(193, 243, 262)
$\frac{1}{2}$ Cd(NO <sub>3</sub> ) <sub>2</sub>	0					113.5	108.2	100.5	97.5	94.0					(109, 245)
	18					68.8	66.9	63.3	61.5	59.7					(95)
	25					107.62	104.90	99.68	97.17	94.20					(72, 109)
	50					124.1	120.9	115.0	112.1	108.7					(60, 116, 185, 245)
	100					178	173	163	158.9	154.0					(99, 133, 191)
$\frac{1}{2}$ Hg <sub>2</sub> (NO <sub>3</sub> ) <sub>2</sub>	0					334.0*	325.0	307.1	293.6†	288.6					(87, 153, 235)
$\frac{1}{2}$ Cu(NO <sub>3</sub> ) <sub>2</sub>	18					507	486.8	461.3 at C = 40	431.4 at C = 80	404.0 at C = 80					(109)
	25					673	639	(599 at C = 40)	(552 at C = 80)	(614 at C = 80)					(191)
	50					790	680 at C = 40	(680 at C = 40)	(604 at C = 80)	(604 at C = 80)					(191)
AgNO <sub>3</sub>	156					818									(191)
	217.8														(191)
	280.9														(191)
	305.7														(191)
	18														(99)
	18														(99)
	0														(99)
	18														(99)
	25														(99)
	50														(99)
	100														(99)
$\frac{1}{2}$ Mn(NO <sub>3</sub> ) <sub>2</sub>	0														(99)
$\frac{1}{2}$ Fe(NO <sub>3</sub> ) <sub>2</sub>	18														(99)
$\frac{1}{2}$ Co(NO <sub>3</sub> ) <sub>2</sub>	0														(99)
	18														(99)
	25														(99)
	50														(99)
	100														(99)
$\frac{1}{2}$ Ni(NO <sub>3</sub> ) <sub>2</sub>	0														(99)
	18														(99)
	25														(99)
	50														(99)
	100														(99)
$\frac{1}{2}$ Cr(NO <sub>3</sub> ) <sub>2</sub>	0														(99)
	18														(99)
	25														(99)
	50														(99)
	100														(99)
	18														(99)
	25														(99)
	50														(99)
	100														(99)

\* At C = 12.5

† At C = 80.



TABLE 2.—(Continued)

	°C	C = 0.5	1	2	3	5	10	20	30	40	50	60	70	100	300	500	700	1000	Lit.
$\text{UO}_2(\text{NO}_3)_2$	0																		(109)
	25						58.2	55.7	51.5	49.9	48.2	44.6	39.2	37.0					(62, 164)
$\text{Al}(\text{NO}_3)_3$	0		64	62.6	60.3	58.2	55.7	51.5	49.9	48.2	44.6	39.2	37.0						(109)
	25		125	120.4	114.0	108.5	102.9	94.8	91.5	87.9	80.5	69.6	65.0						(109)
	50		224	211	194	181	168	151	145	138	126	107	100						(109)
$\text{La}(\text{NO}_3)_3$	0			68.9	(65.3)	62.4	(59.0)	54.0	52.0	49.9	46.0	40.0	37.2						(109)
	18			110.7	(104.8)	100.0	(94.5)	86.6	83.6	80.2	(73.6)	64.0	59.7						(99, 186)
	25		133.5	128.8	(122.2)	116.4	(109.6)	99.6	95.8	91.7	83.4	63.8	56.2						(177, 186)
$\text{Be}(\text{NO}_3)_2$	18			63.1	61.1	59.5	57.6	54.2	52.9	51.4	48.1	42.7	37.9						(99)
$\text{Mg}(\text{NO}_3)_2$	0		(64)	100.7	97.6	94.52	90.8	85.2	82.9	80.4	75.2	67.2	63.9						(109, 110)
	18		109.5	117.3	113.6	109.90	105.6	98.9	97.3	94.0	87.1	70.7	67.2						(48, 105, 185)
	25		119.4		179	173	165	154	149	144	134	117	103						(105, 135, 158)
$\text{Ca}(\text{NO}_3)_2$	0			66.4	64.1	62.2	59.8	55.5	53.1	51.8	47.8	41.5	36.2						(109)
	18		108.34	106.39	103.93	99.39	95.05	88.29	85.38	82.37	75.84	65.61	55.79						(109, 110, 186)
	25		123.6	119.5	115.8	110.9	102.5	99.3	95.7	91.6	85.4	72.2	66.7						(133, 138)
	50			183	177	168	155	150	143	130	113	97.0	86.7						(138, 186)
$\text{Sr}(\text{NO}_3)_2$	0			64.7	62.4	60.2	57.4	53.8	51.1	49.1	44.8	37.9	32.2						(109)
	18		108.16	106.20	102.60	98.90	94.39	87.18	84.17	80.82	73.70	62.64	52.00						(109, 116)
	25		124	119.5	115.3	109.8	101.0	97.7	93.8	89.5	81.7	65.8	59.8						(133, 135)
	50			184	177	168	155	149	143	129	110								(109, 135)
$\text{Ba}(\text{NO}_3)_2$	0		70.0	68.4	66.2	63.6	59.8	54.1	51.5	48.7	42.6								(109)
	18		137.60	133.57	126.34	119.29	110.67	97.18	85.47	72.08									(109, 116, 135, 185)
$\text{Ba}(\text{NO}_3)_2$	0*		111.56	109.35	105.14	100.82	95.53	86.69	81.5	78.83	70.08	56.52							(211)
	18		124.4	120.2	115.8	110.3	100.6	96.3	91.6	87.0	78.8	65.8							(133, 135, 191)
	25			188.8	179.5	169.4	153.9	147.9	140.9	125.5									(87, 109, 135)
	50				321.5	273.1													(109, 140)
	100			351.5															(191)
	156			536															(191)
	217.8			714															(191)
	280.9			827															(191)
	305.7			823															(191)
$\text{LiNO}_3$	0		54.9	54.8	54.6	53.6	51.5	49.4	48.6	47.4	44.7	41.0							(109)
	18		92.58	91.68	90.05	88.33	86.15	82.46	80.85	78.95	74.79	67.80	60.61						(137, 185)
	25		103	102.7	100.6	98.6	95.7	91.0	89.0	86.5	81.7	75.2							(109)
	50				162	157.4	150.8	143.6	141.5	138.8	130.7								(109)
$\text{NaNO}_3$	0		(64.7)	101.65	99.83	97.93	95.43	91.22	89.42	87.04	82.09	73.88	41.9						(109, 135, 245)
	18		102.60	119.1	116.3	113.7	110.7	105.3	102.5	98.7	92.0	83.0	65.72						(48, 137, 185)
	25		120.4	182.3	178.2	174.1	169.3	161.6	157.9	153.4	143.3	128.0							(109, 195)
	50		331.5	326.5	320.5	312.5	302.6	290.4	285.2	280.1	269.0	251.0							(109, 238)
	100		78.89	78.25	77.09	75.60	73.70	70.29	68.8	66.80	63.4	57.4							(263)
$\text{KNO}_3$	0		123.37	122.32	120.21	117.93	114.96	109.62	104.56	104.56	98.53	89.12	80.83						(109, 186, 263)
	18			140.5	138.3	135.7	132.3	126.10	123.3	120.16	113.26	101.4							(137, 185, 263)
	25			212.4	208.9	204.6	199.0	189.4	185.2	180.1	169.0	151.0							(26, 87, 109, 186)
	50		370.6	370.6	363.3	354.8	344.1	326.7	318.7	309.3									(109, 186)
	100		374.7																(186, 263)
	128			461.8															(186)
	156			551.9															(186)
$\text{RbNO}_3$	0																		(49)
	18																		(95)
	30																		(49)
$\text{CsNO}_3$	0		82.4	81.7	80.2	78.5	76.4	72.7	71.0	69.3	65.3	59.0	82						(263, 265)
	18		127.4	126.2	123.6	121.1	117.9	(112.0)	(109.4)	106.4	100.1								(99, 263)
	100		379.0	375.0	367.0	358.6	347.0												(263)

\* Concentrations are  $m$  (= millimole/kg H<sub>2</sub>O) and the conductance data  $10^4 \kappa/m$ .



TABLE 3.—(Continued from p. 231)

[illegible]



<b>I.—(Cont'd)</b>		<b><math>\frac{1}{2}\text{MnSO}_4</math>—(Cont'd)</b>		<b><math>\text{NH}_4\text{NO}_3</math>—(Cont'd)</b>		<b><math>\frac{1}{2}\text{Cu(NO}_3)_2</math>—(Cont'd)</b>		<b><math>\frac{1}{2}\text{Co(NO}_3)_2</math>—(Cont'd)</b>		<b><math>\frac{1}{2}\text{Ca(NO}_3)_2</math>—(Cont'd)</b>	
<b>RbI</b>		<b>C   <math>10^6\kappa/\text{C}</math></b>		<b>C   <math>10^6\kappa/\text{C}</math></b>		<b>C   <math>10^6\kappa/\text{C}</math></b>		<b>C   <math>10^6\kappa/\text{C}</math></b>		<b>C   <math>10^6\kappa/\text{C}</math></b>	
<b>6°</b>		<b>25°</b>		<b>18°</b>		<b>18°</b>		<b>18°</b>		<b>18°</b>	
2 000	81.9	2 000	21.75	2 000	80.5	2 000	45.5	2 000	46.8	2 000	42.7
3 000	79.2	3 000	16.80	3 000	74.2	3 000	36.3	3 000	37.6	3 000	33.5
4 000	74.6	4 000	12.80	4 000	68.4	4 000	28.4	4 000	29.9	4 000	26.5
<b>18°</b>		<b>5 000</b>		<b>5 000</b>		<b>9 872</b>		<b>5 000</b>		<b>6 190</b>	
2 000	101.6	5 000	9.55	5 000	62.3	<b>4.69</b>		<b>23.30</b>		<b>14.15</b>	
3 000	96.8	6 000	7.00	6 000	56.5	<b>AgNO<sub>3</sub></b>		<b><math>\frac{1}{2}\text{Ni(NO}_3)_2</math></b>		<b>9 202</b>	
4 000	89.9	7 000	(4.85)	7 000	50.7	<b>0°</b>		<b>0°</b>		<b>25°</b>	
<b>30°</b>		<b><math>\frac{1}{2}\text{FeSO}_4</math></b>		<b>100°</b>		2 000	36.5	2 000	28.8	2 000	50.5
2 000	121.9	<b>18°</b>		2 000	210	3 000	31.4	3 000	22.8	3 000	38.8
3 000	114.2	2 000	19.5	3 000	183	4 000	27.7	4 000	17.3	4 000	30.0
4 000	105.2	3 000	15.30	4 000	162	5 000	(24.6)	<b>18°</b>		6 130	16.31
<b>SO<sub>4</sub></b>		<b>25°</b>		5 000	142	<b>18°</b>		2 000	46.0	9 110	6.29
<b><math>\frac{1}{2}(\text{NH}_4)_2\text{SO}_4</math></b>		2 000	22.6	6 000	124	2 000	55.9	3 000	37.2	<b><math>\frac{1}{2}\text{Sr(NO}_3)_2</math></b>	
<b>18°</b>		3 000	17.9	7 000	112	3 000	48.4	4 000	29.3	<b>18°</b>	
2 000	60.3	4 000	(13.9)	8 000	99.1	4 000	42.3	5 000	22.7	2 000	38.4
3 000	54.6	<b><math>\frac{1}{2}\text{NiSO}_4</math></b>		9 000	86.3	<b>25°</b>		6 000	16.0	3 000	28.9
4 000	49.5	<b>18°</b>		9 500	79.9	1 500	69.9	<b><math>\frac{1}{3}\text{Cr(NO}_3)_3</math>, 18°</b>		4 000	21.1
5 000	44.6	2 000	19.25	11 600	58.0	2 000	64.0	2 000	43.25	5 000	16.4
6 000	(39.5)	3 000	15.07	13 800	38.8	3 000	55.2	3 000	33.34	<b>25°</b>	
<b>25°</b>		<b>25°</b>		15 000	29.0	4 000	48.5	4 000	25.54	2 000	44.5
2 000	67.8	2 000	22.72	<b><math>\frac{1}{2}\text{Pb(NO}_3)_2</math></b>		5 000	43.0	5 000	18.97	3 000	33.70
3 000	61.7	3 000	17.83	<b>18°</b>		8 460	29.5	<b><math>\frac{1}{3}\text{La(NO}_3)_3</math>, 18°</b>		4 000	25.60
<b><math>\frac{1}{2}\text{ZnSO}_4</math></b>		<b><math>\frac{1}{2}\text{MgSO}_4</math></b>		2 000	30.68	<b>100°</b>		2 000	39.1	4 470	22.56
<b>18°</b>		<b>18°</b>		2 500	27.05	2 000	156	3 000	28.45	<b>NaNO<sub>3</sub></b>	
2 000	20.0	2 000	21.4	<b>25°</b>		3 000	132	4 000	19.92	<b>0°</b>	
3 000	15.60	3 000	16.1	2 000	36.5	4 000	115	<b><math>\frac{1}{2}\text{Be(NO}_3)_2</math>, 18°</b>		2 000	(35.1)
4 000	11.95	4 000	12.0	2 500	31.6	5 000	102	2 000	45.80	<b>18°</b>	
5 000	8.90	5 000	8.8	<b>TiNO<sub>3</sub>, 100°</b>		6 000	92	3 000	37.8	2 000	54.60
<b>25°</b>		<b>25°</b>		2 000	164	7 300	80.7	4 000	31.00	3 000	46.10
2 000	23.20	2 000	25.25	3 000	135	9 580	64.2	5 000	24.85	4 000	39.23
3 000	18.20	3 000	18.95	4 000	115	12 100	51.0	<b><math>\frac{1}{2}\text{Mg(NO}_3)_2</math></b>		<b>KNO<sub>3</sub>, 18°</b>	
4 000	14.18	4 000	14.20	5 000	99	15 100	36.1	2 000	31.5	2 000	69.00
5 000	10.68	5 000	10.40	6 000	86.0	<b><math>\frac{1}{2}\text{Mn(NO}_3)_2</math>, 18°</b>		3 000	26.8	2 500	65.00
<b><math>\frac{1}{2}\text{CdSO}_4</math></b>		<b><math>\frac{1}{2}\text{Li}_2\text{SO}_4</math>, 18°</b>		<b><math>\frac{1}{2}\text{Zn(NO}_3)_2</math>, 18°</b>		2 000	47.5	<b>18°</b>		3 000	(61.3)
<b>18°</b>		2 000	30.39	2 000	47.9	3 000	37.9	<b><math>\frac{1}{2}\text{Fe(NO}_3)_3</math>, 18°</b>		<b>RbNO<sub>3</sub></b>	
2 000	17.92	3 000	23.16	3 000	38.85	4 000	30.30	2 000	48.53	<b>6°</b>	
3 000	13.98	4 000	17.97	4 000	31.08	5 000	23.54	3 000	37.50	2 000	57.1
4 000	10.82	5 000	13.79	<b><math>\frac{1}{2}\text{Cd(NO}_3)_2</math></b>		6 000	17.68	4 000	28.50	<b>18°</b>	
5 000	8.28	<b><math>\frac{1}{2}\text{Na}_2\text{SO}_4</math>, 18°</b>		<b>18°</b>		10 000	4.66	<b>25°</b>		2 000	73.7
<b>25°</b>		2 000	39.6	2 000	40.8	<b><math>\frac{1}{2}\text{Co(NO}_3)_2</math></b>		2 000	54.7	2 500	68.9
2 000	20.5	<b><math>\frac{1}{2}\text{Rb}_2\text{SO}_4</math></b>		3 000	31.4	<b>0°</b>		2 500	49.7	3 000	(64.4)
3 000	16.1	<b>6°</b>		4 000	24.2	2 000	48.53	<b><math>\frac{1}{2}\text{Ca(NO}_3)_2</math></b>		<b>30°</b>	
4 000	12.8	2 000	54.3	5 000	18.4	3 000	37.50	2 000	27.8	2 000	90.5
5 000	10.0	3 000	49.4	6 000	13.7	4 000	28.50	3 000	21.3	2 500	84.5
<b><math>\frac{1}{2}\text{CuSO}_4</math></b>		<b>18°</b>		6 500	11.5	<b><math>\frac{1}{2}\text{Fe(NO}_3)_3</math>, 18°</b>		<b>0°</b>		3 000	(79.2)
<b>18°</b>		2 000	69.9	<b>25°</b>		2 000	46.0	<b>25°</b>		<b>Specific conductance of CaCl<sub>2</sub> solutions (64)</b>	
2 000	19.99	3 000	63.2	2 000	46.0	3 000	35.4	<b>10°C</b>		Wt. %, CaCl <sub>2</sub>	10°C
2 500	17.90	<b>30°</b>		3 000	35.4	4 000	27.21	15°C	15°C	17.9°C	20°C
3 000	(16.2)	2 000	85.8	4 000	27.21	5 000	20.50	17.9°C	17.9°C	20°C	25°C
<b>25°</b>		3 000	77.0	5 000	20.50	6 000	14.08	20°C	20°C	25°C	30°C
2 000	23.2	<b>NO<sub>3</sub></b>		6 000	14.08	6 490	13.33	25°C	25°C	30°C	
2 500	20.9	<b>NH<sub>4</sub>NO<sub>3</sub></b>		<b><math>\frac{1}{2}\text{Cu(NO}_3)_2</math></b>		<b>0°</b>		30°C	30°C		
<b><math>\frac{1}{2}\text{MnSO}_4</math></b>		<b>0°</b>		2 000	29.7	2 000	29.7				
<b>18°</b>		2 000	55.3	3 000	23.4	3 000	23.4				
2 000	18.53	3 000	52.0	4 000	18.3	4 000	18.3				
3 000	14.17	4 000	48.3	5 000	13.98	5 000	13.98				
4 000	10.76	5 000	44.7	6 000	10.49	6 000	10.49				
5 000	8.05	6 000	(41.6)	7 000	7.70	7 000	7.70				
6 000	5.80	7 000	(39.2)	8 000	(4.8)	8 000	(4.8)				
7 000	(3.80)	8 000	(35.6)								
		8 418	31.0								



## PART II. CONDUCTIVITY OF STRONG ELECTROLYTES\*

HENRY C. PARKER AND ALFONS KLEMENC†

CONTENTS	MATIERES	INHALTSVERZEICHNIS	INDICE
Table 1.—Values of $C$ up to 0.5.	Table 1.—Valeurs de $C$ jusqu'à 0,5.	Tabelle 1.—Werte von $C$ bis 0,5.	Tabella 1.—Valori di $C$ fino a 0,5.
Table 2.—Values of $C$ from 0.5 to 1000.	Table 2.—Valeurs de $C$ de 0,5 à 1000.	Tabelle 2.—Werte von $C$ von 0,5 bis 1000.	Tabella 2.—Valori di $C$ da 0,5 a 1000.
Table 3.—Values of $C$ above 1000.	Table 3.—Valeurs de $C$ au dessus de 1000.	Tabelle 3.—Werte von $C$ über 1000.	Tabella 3.—Valori di $C$ sopra 1000.

TABLE 1.—VALUES OF  $C$  UP TO 0.5For Literature References, *v.* Table 2B-Table.—Standard arrangement; *v.* Vol. III, p. viii

$\text{HCl}$ , 25°		$\frac{1}{2}\text{Ca}(\text{HCO}_3)_2$ , 25°		$\text{Na}_5\text{C}_{11}\text{H}_2\text{O}_{10}$ , Benzenepentacarboxylate	
$C$	$\Lambda$	$C$	$\Lambda$	$C$	$\Lambda$
0.05	424.84	0.1	(109.5)	0°	
0.1	424.64	0.2	(106.0)	0.2	245
0.2	424.24	0.3	104.2	25°	
0.3	423.84			0.2	483
				50°	
				0.2	774
$\text{HIO}_3$ , 25°		$\frac{1}{2}\text{Ca}(\text{C}_2\text{H}_3\text{O}_2)_2$ , 18°		$\text{Na}_5\text{C}_{11}\text{HO}_{10}$ , Benzenepentacarboxylate	
$C$	$\Lambda$	$C$	$\Lambda$	$C$	$\Lambda$
0.01	388.96	0.1	82.2	0°	
0.02	388.90			0.2	325
0.03	388.85			25°	
0.05	388.74			0.2	640
0.1	388.47			50°	
0.2	387.93			0.2	1019
0.3	387.40				
$\frac{1}{2}\text{H}_2\text{SO}_4$ , $t$ , °C		$\frac{1}{4}\text{Sr}_2\text{Fe}(\text{CN})_6$ , 0°		$\text{NaC}_4\text{H}_7\text{BrO}_2$ , $\alpha$ -Bromobutyrate	
$C = 0.2$	$\Lambda$	$C$	$\Lambda$	$C$	$\Lambda$
18	374.4	0.2	66.8	0°	
25	417.9			0.24	46.1
50	566.1			15°	
75	692.6			0.24	70.6
100	779			25°	
128	806			0.24	89.7
156	758			35°	
$\text{HNO}_3$ , $C = 0.3$		$\text{LiIO}_3$ , 18°		$\text{KClO}_3$ , 18°	
$C$	$\Lambda$	$C$	$\Lambda$	$C$	$\Lambda$
18	373.7	0.1	66.57	0.1	118.45
		0.2	66.34	0.2	118.17
$\text{H}_3\text{PO}_4$ , $C = 0.2$		$\text{LiClO}_4$ , 0°		$\text{KClO}_4$ , 100°	
$C$	$\Lambda$	$C$	$\Lambda$	$C$	$\Lambda$
18	330.4	0.2	54.3	0.2	371.5
25	366.8				
50	492.4			$\text{KIO}_3$ , 18°	
75	599.6			$C$	$\Lambda$
100	687.7			0.1	97.50
128	761.2			0.2	97.20
156	803.7			25°	
$\text{TiH}(\text{C}_2\text{H}_3\text{O}_2)$ , $C = 0.2$		$\text{NaClO}_3$ , 18°		0.2	112.84
$C$	$\Lambda$	$C$	$\Lambda$	$\frac{1}{2}\text{K}_2\text{C}_2\text{O}_4$ , 18°	
18	373	0.1	97.4	$C$	$\Lambda$
		0.2	97.0	0.1	94.4
$\frac{1}{2}\text{MgC}_2\text{O}_4$ , 18°		$\text{NaBrO}_3$ , 18°		0.2	86.9
$C$	$\Lambda$	$C$	$\Lambda$		
0.1	94.4	0.1	90.8		
0.2	86.9	0.2	90.5		
		$\text{NaIO}_3$ , 18°			
		$C$	$\Lambda$		
		0.1	76.58		
		0.2	76.33		
		$\text{NaHCO}_3$ , 25°			
		$C$	$\Lambda$		
		0.1	(97.4)		
		0.2	(96.0)		
		0.3	95.2		
		$\text{NaC}_2\text{H}_3\text{O}_2$ , 18°			
		$C$	$\Lambda$		
		0.1	77		
		0.2	76.5		

\* Except halides, nitrates and sulfates, for which see p. 230, and soap solutions, for which see Vol. V, p. 458.

† Critical compilation by Henry C. Parker. Graphical interpolation to round values of  $C$  by Alfons Klemenc.

$\frac{1}{2}\text{KHC}_2\text{O}_4$ , 18°		$\frac{1}{2}\text{K}_2\text{C}_2\text{H}_4\text{O}_4$ , Phthalate, 25°		$\text{KC}_8\text{H}_7\text{N}_3\text{O}_7$ , Picrate, 0°	
$C$	$\Lambda$	$C$	$\Lambda$	$C$	$\Lambda$
0.2	274.0			0.2	54.9
0.3	247.8	0.4	(123.3)	18°	
				0.2	88.7
		$\text{KHC}_8\text{H}_7\text{O}_4$ , Biphthalate, 25°		$\text{KCNS}$ , 18°	
		$C$	$\Lambda$	$C$	$\Lambda$
		0.1	152.7	0.1	119.94
		0.2	141.8	0.2	119.74

TABLE 2; see p. 242 to 253

TABLE 3.—VALUES OF  $C$  ABOVE 1000For Literature References, *v.* Table 2B-Table.—Standard arrangement; *v.* Vol. III, p. viii

$\text{HCl}$ , 18°		$\text{HI}$ , 18°		$\frac{1}{2}\text{H}_2\text{SO}_4$ —(Cont'd)	
$C$	$10^3\kappa/C$	$C$	$10^3\kappa/C$	$C$	$10^3\kappa/C$
2 000	253.8	2 000	254.4	32 390	3.188
3 000	214.7	3 000	(212.8)	33 340	3.219
4 000	(182)	4 000	178.4	33 800	3.232
5 000	152.0	5 000	146.7	34 260	3.215
10 000	64.3			34 710	3.155
		$\text{HIO}_3$ , 18°		35 580	2.876
		$C$	$10^3\kappa/C$	$\text{HNO}_3$ , 18°	
		2 000	106.0	$C$	$10^3\kappa/C$
		3 000	(85.0)	2 000	259.1
		4 000	70.4	3 000	220.0
$\text{HClO}_3$ , 18°		$\frac{1}{2}\text{H}_2\text{SO}_4$ , 0°		4 000	184.4
$C$	$\Lambda$	$C$	$\Lambda$	5 000	154.6
2 000	246.7	1 012	27.9	6 000	129.1
3 000	205.0	1 936	20.4	7 000	108.6
$\text{HClO}_4$ , 25°		$\frac{1}{2}\text{H}_2\text{SO}_4$ , 20°		8 000	91.9
$C$	$\Lambda$	$C$	$\Lambda$	9 000	77.6
2 000	291.5	1 012	33.4	10 000	64.9
3 000	226.0	1 936	24.5	16 500	20.43
4 000	185.7	$\frac{1}{2}\text{H}_2\text{SO}_4$ , 25°		17 000	17.65
5 000	150.0	$C$	$\Lambda$	18 000	12.55
6 000	118.4	1 012	34.1	19 000	8.50
7 000	91.0	1 936	24.9	20 000	5.50
8 000	68.4	$\frac{1}{2}\text{H}_2\text{SO}_4$ , 18°		21 000	2.90
9 000	52.0	$C$	$\Lambda$	22 385	1.009
10 000	41.4	2 000	182.7	22 870	0.6690
11 000	31.7	3 000	166.5	23 660	0.8538
12 000	23.1	4 000	150.5	23 800	1.667
13 000	16.4	5 000	134.6	24 060	1.720
		6 000	119.1	$\frac{1}{2}\text{H}_3\text{PO}_4$ , 25°	
		7 000	105.0	$C$	$\Lambda$
		8 000	92.3	2 000	289.8
		9 000	80.8	3 000	242.2
		10 000	70.3	$\frac{1}{3}\text{H}_3\text{PO}_4$ , 0°	
		11 000	(60.6)	$C$	$\Lambda$
		16 248	28.12	2 000	24
		23 047	9.35	6 000	14.3
		27 180	4.54	7 000	13
		29 840	3.32	8 000	11.7
		30 900	3.17	11 000	11.3
		31 410	3.145	12 000	11
		31 900	3.165		
$\text{HBr}$ , 18°					
$C$	$\Lambda$				
2 000	253.3				
3 000	213.1				
4 000	176.4				
5 000	145.9				

Continued on p. 254



TABLE 2—VALUES OF  $\lambda$  BETWEEN  $C = 0.5$  AND  $1000$ , \* STANDARD ARRANGEMENT; v. Vol. III, p. viii

Solute	$^{\circ}\text{C}$	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
HCl	0		261.4	260.6	259.1s	257.2	254.4s	249.87	247.80	245.30					(212); cf. (14, 109)
	12.6														(109)
	18		377	375.5	372.4	369.3	364.9	357.6	354.1	350.1	341.5	326.6	316.6	300.5	(79, 128, 135, 157, 183); cf. (31)
	19.8														(224)
	20														(103.5, 145)
	25	423.04	421.38	419.17	415.6	412.0	407.3	399.0	393.9	389.8	381.8	360.6	348.5	331.9	(163.5)
	25				415.11	411.08	406.07	397.80			379.6	359.2		332.8	(24, 145, 198); cf. (31)
HClO <sub>4</sub>	35						470	460	455	450	436	408.6	392.2	374.8	(109, 135)
	18								(347.6)	343.6	334.6	316.6	306.2	291.4	(93, 95); cf. (48)
	25				400	396	391	382	379	375	366	352			(195)
HClO <sub>4</sub>	25				405	405	402	393.0	389.0	384.4	373.8	359.0	352.5	342.5	(150, 195, 246)
HBr	18									355.2	347.7	328.4	316.5	301.1	(95)
	25					418	410.7	400.2	396.0	391.2	380.7	362.3	351.0	334	(56, 196)
	25		400	395	386	377	366								(196)
HBrO <sub>3</sub>	25														(93, 155)
HI	18		420.0	418.2	415.2	412.0	407.8	400.8	397.4	393.2	383.4	367	351.6	296.8	(195, 249, 266)
	25		344.59							252.3	219.7	174.5	158.4	141.2	(95, 141)
HIO <sub>3</sub>	18		383.95	379.93	370.85	359.69	343.04	310.66	295.60	278.34	242.18	219.5	191.6		(83, 141, 195)
	25	386.34	386	372	335	297	253	192	172	150	110				(195)
HIO <sub>4</sub>	25														(151)
H <sub>2</sub> SO <sub>4</sub>	0														(151)
	20														(151)
	25														(151)
	25														(151)
	0														(109, 109)
H <sub>2</sub> SO <sub>4</sub>	0†														(211)
	18	371.3	471.7	456.3	426.4	399.0	369.3	333.3	243.5	232.9	234.3	222.5	(For 35°C, v. (109))	198.6	(75, 105, 128, 127, 154)
	25	413.1	(399.5)	390.3	(364.9)	336.4	308.0	272.6	261.5	250.8					(105, 109, 184)
	50	552.6	(528)	500.6	(448)	405.4	367.5	322.9	309.8	299.9					(154)
	75	656.1	(608)	560.0	(481)	434.4	395.7	355.5	345.0	335.9					(154)
	100	705		570	(488)	445	414	384	375	368					(154)
	128	695		550	(485)	(458)	438	416	410	403					(154)
	156	643		535	(498)	480	(463)	447	442	434					(154)
	218	585		562	(545)	532	521	501	492	482					(154)
	306			636											(154)
H <sub>2</sub> SeO <sub>4</sub>	18					258.4	237.6	199.6	184.6	168.0					(107)
H <sub>2</sub> SeO <sub>4</sub>	25			414	410	405	399	389	385	379	367				(195)
H <sub>2</sub> SeO <sub>4</sub>	25			421	414	408	400	388	383	378	367				(195)
H <sub>2</sub> SeO <sub>4</sub>	25			384	366	349	328	295	283	272	253	233	220	219	(195)
H <sub>2</sub> TeO <sub>4</sub>	25	17.9		6.3	2.9	1.8s	1.30	0.73							(231)
HNO <sub>3</sub>	0					253.4	251.7	248.6	247.1	245.3	241.3				(109)
	18	373.3	372.6	370.6	366.8	364.0	360.4	353.0	349.6	345.7	336	321.5	315.5	305.5	(79, 122, 135, 184, 255)
	25	416.2	414.6	412.9	411.2	407.3	402.4	394.0							(163.5)
	25				409.0	405.2	400.8	392.5	388.7	384.2	376.1	356.5	347.0	329.8	(109, 184, 246)
	35					455.8	450.4	441.4	437.4	432.6	419.0				(109)
	50	562.8	(560.7)	557.7	(552)	546.0	(540)	527.4	(521.9)	514.7					(184)
	75	695.7	(692.3)	688.3	(681.6)	674.7	665.2	647.6	639.6	630.6					(184)
	100	813.2	(809)	804.6	(795)	784.5	(772)	748.6	737.7	727.0					(184)
	128	928		917	(904)	891	(872)	843	(830)	815					(184)
	156	1026	(1018)	1010	(993)	976	(954)	915	(898)	878					(184)
	218			1164											(184)
	306			1154											(184)
NH <sub>4</sub> NO <sub>3</sub>	20														(216.5)
NH <sub>4</sub> ClO <sub>4</sub>	18														(99)
NH <sub>4</sub> IO <sub>3</sub>	0														(267)
	25		60.6	60.2	58.7	57.0	55.0	52.1	482		96.0	90.2		83.8	(267)
		114	113	110	109	106	103	97							(267)

\* When the literature cited contains data at other temperatures this is indicated thus: (Also at 25°C). † Values of  $C$  are for  $t = 0^{\circ}\text{C}$ . (For 10, 30, 40, 50, 60, 70°C, v. (151).) ‡ Concentrations are  $m$  ( = millimole/kg H<sub>2</sub>O) and  $\lambda$  values are  $10^4 \text{ cm}^2/\text{m}$ .



TABLE 2.—(Continued)

Solute	°C	C	0.5	1	2	5	10	30	50	70	100	200	500	700	1000	Lit.
NH <sub>4</sub> HSO <sub>4</sub>	0			316	308	292	275	253	223	213	202.2		165.2			(109)
H <sub>3</sub> PO <sub>4</sub>	25			514	492	454	416	372	(275 at C = 125)				226			(109)
H <sub>2</sub> PO <sub>4</sub>	18			(For 17°C, <i>v.</i> (12))	282.8	(273.0)	202.7	(166.7)	122.5	(108.7)	96.4		31.7	30	28.2	(204); cf. (41)
H <sub>2</sub> PO <sub>4</sub>	25				311.5		221.7	(180.3)	132.4	(117.7)	103.9					(184)
	50				400.2		272.7	(216)	157.6	(139.2)	122.5					(184)
	75				463.0		299.6	(236)	168.4	(148.4)	120.7					(184)
	100				463.0		307.6	(236)	167.6	(148.2)	128.2					(184)
	128				507.0		297.6	(226)	157.8	(138.0)	120.0					(184)
	156				488.4		273.6	(206)	141.8	(123)	107.6					(184)
H <sub>4</sub> P <sub>2</sub> O <sub>7</sub>	25					151.6	136.4	122.5	107.6	103.1	98.6					(254)
H <sub>4</sub> P <sub>2</sub> O <sub>7</sub>	20			627	565	489	443.7	405.8								(254)
NH <sub>4</sub> PO <sub>4</sub>	18					19.5	18.9	18.2	17.2	16.8	16.4	15.6	14.1			(250)
(NH <sub>4</sub> ) <sub>2</sub> PO <sub>4</sub>	0					35.7	34.5	33.7	32.4	31.7	30.9	29.1	26.1			(267)
(NH <sub>4</sub> ) <sub>2</sub> PO <sub>4</sub>	25					43	42	41.0	30.4	38.6	37.6	35.2	31.6			(267)
(NH <sub>4</sub> ) <sub>2</sub> PO <sub>4</sub>	17															(13)
(NH <sub>4</sub> ) <sub>2</sub> PO <sub>4</sub>	17															(13)
H <sub>2</sub> AsO <sub>4</sub>	25			308.2	279.8	230.0	187.0	150.8	103.4	91.4	80.0					(261)
H <sub>2</sub> AsO <sub>4</sub>	18					92.9	91.4	89.0	84.9	82.7	(79.5)	(73.2)	(63.8)	(59.6)	54.7	(95, 167, 169)
NH <sub>4</sub> C <sub>2</sub> H <sub>3</sub> O <sub>7</sub>	100						299.2		(286.0 at C = 25)							(169)
	156						455		(525 at C = 25)							(169)
	218						81.4	319.1	(81.8 at C = 29.35)							(169)
	306															(169)
Various substituted ammonium nitrites																
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	27.5				115.3	111.2	108.3	105.3	CH(CN)NO <sub>2</sub> COONH <sub>4</sub>							(215-9, 217)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	27.5			115.2	113.2	109.7	105.9	101.4	CONH <sub>2</sub> CHNO <sub>2</sub> COONH <sub>4</sub>							(253)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	27.5				109.2	104.7	101.1	97.4	(NH <sub>4</sub> O <sub>2</sub> C) <sub>2</sub> CHNO <sub>2</sub>							(253)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	25			77.2	76.3	74.2	(72.2)	Piperidine cyanoacetate								(172)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	0			30.4	29.6	28.9	28.1	26.9	Tetraethylammonium picrate							(263)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	18			51.9	50.6	49.3	47.8	45.8								(263)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	100			189.2	185.7	179.7	173.2	164.3								(263)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	25			56.6	55.2	52.9										(263)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	18			114.1	112.9	110.8										(263)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	25			133.1	131.8	129.4	126.8	123.2	Diethylphenylammonium 3-5-dinitrobenzoate							(172)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	18			108.1	107.1	(106.4 at C = 3)	109.6	116.4	CH <sub>3</sub> NH <sub>2</sub> HCl	117.1	114.2	(Also at 32.35°C)				(34, 172)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	25			125.7	124.4	122.0			(CH <sub>3</sub> ) <sub>2</sub> NH <sub>2</sub> HCl	110.6	107.9					(172)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	18			101.8	100.6											(34, 172)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	25			120.1	119.0	(117.9 at C = 3)										(172)
C <sub>2</sub> H <sub>5</sub> BrNO	25					92.8	91.9	89.7	82.9	79.6						(172)
C <sub>2</sub> H <sub>5</sub> BrNO	25					92.8	91.9	89.7	82.9	79.6						(308)
C <sub>2</sub> H <sub>5</sub> NI	56					74.1	72.9	71.5	60.1	68.2						(269)
NH <sub>4</sub> CNS	0			76.5	75.4											(230)
	18					134.8	132.7	128.6	123.9	121.6	67.1	64.2	93.8	91.7	89.7	(267)
	25					161	158	154	148	145	104.1	99.5	114.0			(93, 98)
	35					198	183	175	165	161	155	146	129	119	108	(48, 267)
	0					32.9	27.8	23.1	16.9	14.7	12.7	9.5	5.9			(48, 267)
	18					61.8	52.1	43.5	32.1	28.0	21.4	15.9	10.1	8.37	6.67	(77)
	25					74	62	52	38	34	24.2	18.2	11.8			(195)
	30										29	22	14			(195)
	25															(195)
	20										206	188				(195)
	25															(195)
	25															(72)
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24

Solute	°C	C	0.5	1	2	5	10	20	50	70	100	300	500	700	1000	Lit.
TiHSO <sub>4</sub>	18		493.0	477.5	(454.4)	413.0	376.0	337.4	289.6	275.5	262.0	(248.2 at C = 150)				(65)
TiSeO <sub>4</sub>	25			130.4	123.2	111.9	102.2	90.9								(72)
TiSeO <sub>4</sub>	25			141.9	138.4	132.7	126.2	117.4								(72)
TiPO <sub>4</sub>	25			122.7	122	114.5										(72)
TiH <sub>2</sub> PO <sub>4</sub>	25					35.7	34.9	33.8	32.1							(72)
TiH <sub>2</sub> AsO <sub>4</sub>	25				(36.5)	35.6	34.9	33.9	32.1							(72)
TiH <sub>2</sub> AsO <sub>4</sub>	25				56.4	55.7	54.6	52.8	49.2							(72)
TiCO <sub>3</sub>	25			143.0	136.9	126.2	115.0	102.4								(72)
TiH(C <sub>2</sub> H <sub>3</sub> O <sub>4</sub> )	18		282	250.6		104.2	93.9	85.2								(65)
Zn(ClO <sub>3</sub> ) <sub>2</sub>	18										73.9	69.0	61.7	58.4	54.3	(93, 95); cf. (47)
Zn(NO <sub>3</sub> ) <sub>2</sub>	18												51.3	47.6	43.2	(99)
Zn(BrO <sub>3</sub> ) <sub>2</sub>	18															(215.5)
Zn(NO <sub>2</sub> ) <sub>2</sub>	20															(109)
Zn(C <sub>2</sub> H <sub>3</sub> O <sub>4</sub> ) <sub>2</sub>	0			44.6	43.2	40.8	38.8	36.8	31.4	29.1	26.6	22.0	14.8	19.1	11.8	(109, 239)
	25			90.7	86.1	79.2	73.7	67.6	57.4	53.0	48.5	39.2	25.3			(109)
	35			106	103	97	91	83	70		59	46	19			(109)
	18										75.0	69.9	62.1	58.6	54.3	(93, 95)
Cd(ClO <sub>3</sub> ) <sub>2</sub>	20															(214)
Hg(NO <sub>3</sub> ) <sub>2</sub>																(216)
Hg <sub>2</sub> NNO <sub>2</sub> ·H <sub>2</sub> O																(215)
HgNCl <sub>2</sub> ·H <sub>2</sub> O																(164)
HgCH <sub>2</sub> OH																(164)
HgC <sub>2</sub> H <sub>3</sub> O <sub>4</sub>																(215)
Hg <sub>2</sub> C <sub>2</sub> Cl <sub>2</sub> ·H <sub>2</sub> O																(247)
Hg <sub>2</sub> C <sub>2</sub> H <sub>3</sub> O <sub>4</sub>																
HgC <sub>2</sub> H <sub>3</sub> N <sub>2</sub> , etc.																
Cu(ClO <sub>3</sub> ) <sub>2</sub>	18				67.7	57.0	48.7	40.6	30.2	(26.7)	[Hg(SC <sub>2</sub> H <sub>3</sub> ) <sub>2</sub> ·Hg(C <sub>2</sub> H <sub>3</sub> O <sub>4</sub> ) <sub>2</sub> ]					(93, 95); cf. (47)
Cu(NO <sub>3</sub> ) <sub>2</sub> and Cu(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub>	18															(123, 215.5)
Cu(C <sub>2</sub> H <sub>3</sub> O <sub>4</sub> ) <sub>2</sub>	18															(95, 99)
AgClO <sub>4</sub>	25			111.0	109.1	105.4	102.0	(98.1)								(32)
AgClO <sub>3</sub>	25			124.1	123.5	121.8	119.7	113.2								(153)
AgClO <sub>2</sub>	25			128.0	127.1	124.7	122.6	119.8								(153)
AgSO <sub>4</sub>	25			159.6	156.0	151.2	146.0	137.8								(153)
AgHSO <sub>4</sub>	18		481	463	439.2	402.0	365.5	327.0								(65)
AgNO <sub>3</sub>	25				128.3	115.6	112.3	85.4								(53); cf. (179)
AgPO <sub>3</sub>	18															(250)
AgC <sub>2</sub> H <sub>3</sub> O <sub>2</sub>	25			101.2	100.1	97.1	(99.0 at C = 3)									(153, 225); cf. (106)
AgC <sub>2</sub> H <sub>3</sub> CO <sub>2</sub>	25															(225)
AgSO <sub>3</sub> C <sub>2</sub> H <sub>4</sub>	25			96.8	96.2	94.5	92.0	79.6								(153)
AgSO <sub>3</sub> C <sub>2</sub> H <sub>4</sub>	25			89.0	87.6	85.6	83.0									(153)
AgSO <sub>3</sub> C <sub>2</sub> H <sub>4</sub>	25			101.3	99.8	97.6	95.5	(93.2)								(153)
AgSiF <sub>6</sub>	25			117.5	116.4	113.8	110.8	107.4								(153)
[Ir(NH <sub>3</sub> ) <sub>2</sub> Br]Br <sub>2</sub>	95		753	727	695	641	596									(143)
[Pt(NH <sub>3</sub> ) <sub>2</sub> (NH <sub>2</sub> OH)]Cl <sub>2</sub>	18															
Pt <sub>2</sub> N <sub>2</sub> H <sub>2</sub> X <sub>2</sub> O <sub>4</sub> , etc.																
H <sub>2</sub> Pt(CN) <sub>4</sub>	25				406	405	402	395	381							(261)
H <sub>2</sub> MnO <sub>4</sub>	25				402	400	395	389	378							(161)
MnCl <sub>2</sub> ·Hg(CN) <sub>2</sub> ·2H <sub>2</sub> O	23			245	237											(86)
AgMnO <sub>4</sub>	25			119.9	119.2	117.5	115.4	(111.9)								(72)
FeNH <sub>4</sub> O <sub>2</sub> Si <sub>2</sub>																
H <sub>2</sub> Fe(CN) <sub>4</sub>	25		1360	1290	1210	1110	1040	970	890							(271)
FeC <sub>2</sub> N <sub>2</sub> H <sub>2</sub> O	25			261	(253)	242.0	233.6	224.3	210.							(196)
FeC <sub>2</sub> N <sub>2</sub> H <sub>2</sub> O <sub>12</sub>																(49)
FeC <sub>2</sub> N <sub>2</sub> H <sub>2</sub> O	25			232.9	226.0	214.9	204.8	192.7								(123)
FeC <sub>2</sub> N <sub>2</sub> H <sub>2</sub> O	25			207	201	189	178	164	142							(40)
FeC <sub>2</sub> N <sub>2</sub> H <sub>2</sub> O	25			219.7	213.0	202.1	192.3	180.8	161.8							(40)
FeC <sub>2</sub> N <sub>2</sub> H <sub>2</sub> O	25			204.9	197.5	185.8	172.3	157.8	143.7							(40)
FeC <sub>2</sub> N <sub>2</sub> H <sub>2</sub> O <sub>4</sub>																(40)
Pyridine disulfatoferrate																
Co(ClO <sub>3</sub> ) <sub>2</sub>	18															(270.5)
Co <sub>2</sub> N <sub>2</sub> H <sub>2</sub> O <sub>4</sub>	0			265.0	257.0	247.8	240.1	230.7								(99)
Co(NH <sub>3</sub> ) <sub>2</sub> (OH) <sub>2</sub>	0			154.2		142.0		132.1								(144)
	25			275		242		224								(144)



TABLE 2.—(Continued)







TABLE 2.—(Continued)

Solute	°C	0.5	1	2	5	10	20	30	50	70	100	300	500	700	1000	Lit.
$\text{LiClO}_4$	0	54.1	53.7	53.3	52.5	51.5	50.3									(263)
	18	87.4	86.9	86.2	84.6	83.0	81.0									(263)
	25		112.8	111.4	108.9	106.5	103.9									(195)
$\text{LiIO}_3$	100	290.6	287.6	284.6	278.6	272.6	264.1									(263)
	18	65.78	65.18	64.34	62.80	61.15	58.97		55.18	53.45	51.43	46.81	38.93	35.35	31.17	(92, 129); cf. (47, 99)
$\text{LiNO}_3$	20															(215.5)
$\text{Li}_2\text{CO}_3$	18															(126); cf. (267)
$\text{LiHCO}_3$	18															(99)
$\text{LiC}_2\text{H}_3\text{O}_5$	18															(95)
$\text{LiC}_4\text{H}_7\text{N}_3\text{O}_7$	0	33.6	33.4	33.1	32.4	31.7	30.8									(263)
	18	56.9	56.5	56.0	54.8	53.8	52.1									(263)
	100		209.2	207.2	202.2	196.7	190.2									(263)
$\text{LiCNS}$	18															(93)
$\text{LiMnO}_4$	25		101.2	98.8	95.8	92.4	89.3		49.0	47.2	45.2	41.0	(Also at 15°C)	61.4	57.8	(72)
$\text{Li}_2\text{CrO}_4$	0		59	57.6	56.2	55.1	53.3									(267)
	18															(93, 95)
	25		111	110.3	108.3	105.4	101.0		92.9	89.2	85.3	77.1	57.4	53.2	48.3	(267)
	35		134	134	132	129	124		113		103.0	93.2	66.0	62.8	58.6	(267); cf. (47, 49)
$\text{Li}_2\text{Cr}_2\text{O}_7$	18															(99)
$\text{NaOH}$	0															(23)
	18			213.5	210.8	208.4	205.5		200.3	198.0	195.3	189.0	175.5	168.0	158.4	(23, 97, 126, 128, 187, 209)
	25															(77, 117)
	50															(23)
	100			581.1		(234.0)	230.0		224.0	221.4	218.2	210.0	(202.5 at C = 300)		260.6	(23, 187)
	156			812.3			558.5		539.4	(575.7 at C = 4)	(803.6 at C = 4)	(744.9 at C = 40)			406.8	(187)
	218						929		872	(1001 at C = 4)	(898 at C = 40)					(187)
$\text{NaClO}_3$	0		59.8	59.6	58.9	57.6	56.1		(53.7)	52.6	51.3	(48.3)	(43.6)			(109)
	18	96.3	95.56	94.68	92.8	91.08	88.71		84.65	82.85	80.8	76.43	69.12	65.80	61.8	(48, 69, 95)
	25		(113.0)	111.4	108.8	106.4	103.4		(98.5)		(94.0)	(88.3)	79.5			(69, 109, 195)
	35			134	132	129	125		119		113	106	96			(109)
$\text{NaClO}_4$	18															(93)
	25		123.4	121.7	119.1	116.6	113.5		(For 0, 12.5, 35°C, v. (109))					68.6	65	(195); cf. (109, 261)
$\text{NaBrO}_3$	0		56.5	56.0	54.4	53.0	51.2		48.6	47.4	46.1					(267)
	18	89.73	89.09	88.04	86.23	84.4	82.1		78.0	76.1	73.9	69.1	61.7	58.4	54.4	(69, 99)
	25		105	103	100.5	98.8	95.5		90.5	88.2	85.6					(267)
$\text{NaIO}_3$	18	75.72	75.08	74.20	72.52	70.76	68.48		64.34	62.50	60.37	55.37				(129)
$\text{Na}_2\text{IO}_6$	25						159.4									(261)
$\text{Na}_2\text{H}_2\text{IO}_4$	25						20.3		19.7	19.4	19.0					(261)
$\text{Na}_2\text{H}_4\text{IO}_6$	25						38.7		33.8	31.8						(261)
$\text{Na}_2\text{H}_2\text{SiO}_4$	25			44.6	43.7	41.7	38.7		69.2							(261)
$\text{Na}_2\text{H}_4\text{SiO}_6$	25				82	81.3	78.8		76.8	76.7	76.4	75.2	(72.2)	(70.7)	68.7	(108)
$\text{Na}_2\text{S}$	0								152	151	149	145	(129)	(120)	110.2	(108); cf. (18)
	18								177	174	171	162	143	135	125.8	(108)
	25										155	(153 at C = 150)	(146 at C = 300)			(77)
$\text{Na}_2\text{S}_2$	25															(77)
$\text{Na}_2\text{S}_2\text{O}_3$	0		133	129	123	119	113		103							(267)
	25		254	248	236	226	214		195	187	177	159	(Also at 15 and 35°C)			(267)
$\text{Na}_2\text{S}_2\text{O}_4$	0															(107)
	18		186.1	181.8	(90.6 at C = 7.8)	(31.25)	(75.5 at C = 125.0)		144.2	138.3	131.5					(107)
	25		198.3 at C = 7.8	(180.9 at C = 31.25)												(107)
$\text{Na}_2\text{S}_2\text{O}_5$	25															(260)
$\text{Na}_2\text{S}_2\text{O}_6$	25															(267)
$\text{Na}_2\text{HS}$	0	271	268	265	245	236	223		201							(108)
	18								57.9	56.8	55.6	(Also at 0, 15, 35°C)		45.1	42.5	(108)
	25								87.6	86.0	84.1	79.9	72.9	69.6	65.5	(108)
$\text{Na}_2\text{HSO}_4$	0								100.9	99.1	97.1	92.4	84.2	80.4	76.0	(108); cf. (77)
	25															(151)
$\text{Na}_2\text{H}_2\text{SO}_4$	25															(10, 151)
$\text{Na}_2\text{H}_4\text{SO}_6$	25	262.8	254.5	236.8	218.5	197.35	168.62		44.6	43.9	(Also at 50 and 70°C)					(192); cf. (10)
$\text{Na}_2\text{H}_6\text{SO}_6$	25	119.9	117.3	113.3	109.4	104.1	101.1		148.27	158.5	148.27	130.64				(261)
$\text{Na}_2\text{H}_8\text{SO}_6$	25			58.8		55.9			(57.4 at C = 4)							(32)







TABLE 2.—(Continued)

[illegible]



TABLE 2.—(Continued)

[illegible]



TABLE 2.—(Continued)











TABLE 3.—(Continued from p. 241)

$\frac{1}{2}\text{H}_3\text{PO}_4$ —(Cont'd)	$\frac{1}{2}\text{Mg}(\text{C}_2\text{H}_3\text{O}_2)_2$	$\frac{1}{2}\text{Ba}(\text{ClO}_3)_2$	C	$10^6\text{K}/\text{C}$	$\text{NaOH}$ —(Cont'd)	C	$10^6\text{K}/\text{C}$	$\text{NaClO}_3$ —(Cont'd)	C	$10^6\text{K}/\text{C}$	$\text{NaC}_2\text{H}_3\text{O}_2$ , 18°	C	$10^6\text{K}/\text{C}$	
C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	
14 700	9.3	2 000	14.8	1 500	37.9	7 000	22.6	13 000	104.9	2 000	30.0	2 000	30.0	
22 000	6.3	3 000	8.8	2 000	(34.4)	8 000	16.3	14 000	96.2	3 000	22.0	3 000	22.0	
33 700	2.3	4 000	4.85	18°		9 000	11.9	15 000	88.7	4 000	(15.6)	4 000	(15.6)	
39 600	1.2	5 000	2.61	2 000	44.7	10 000	8.60	16 000	82.3	5 000	10.5	$\text{NaC}_2\text{H}_3\text{CO}_2$ , 18°		
50 400	0.44	6 000	1.30	30°		11 000	6.30	17 000	76.4	2 000		2 000	24.8	
57 700	0.24	6 550	0.770	1 500	62.4	12 000	4.55	18 000	77.5	3 000		3 000	16.63	
$\text{H}_3\text{PO}_4$ , 18°		7 744	0.218	2 000	(55.7)	13 000	3.40	19 000	67.7	4 000		4 000	10.89	
1 076	52.53	25°		$\frac{1}{2}\text{Ba}(\text{C}_2\text{H}_3\text{O}_2)_2$ , 18°		14 000	2.60	$\text{NaClO}_3$ , 18°		2 000		$\text{NaCNS}$ , 18°		
1 658	51.18	2 000	17.4	2 000	22.43	15 000	2.00	2 000	51.7	2 000		2 000		
3 613	45.72	3 000	10.4	3 000	(14.8)	16 000	1.65	3 000	43.5	3 000		3 000		
5 930	35.13	5 000	3.41	4 000	9.20	17 000	1.34	4 000	36.1	4 000		4 000		
7 716	25.59	6 550	1.08	$\frac{1}{2}\text{Ba}(\text{C}_2\text{H}_3\text{CO}_2)_2$		18 000	1.10	$\text{NaClO}_4$ , 18°		2 000		3 000		
10 820	13.23	7 744	0.333	18°		19 000	0.900	2 000	54.97	3 000		4 000		
15 086	4.662	$\frac{1}{2}\text{MgCrO}_4$ , 18°		2 000		3 000	129.4	3 000		46		$\frac{1}{2}\text{Na}_2\text{SiO}_3$		
$\text{NH}_4\text{C}_2\text{H}_3\text{O}_2$ , 18°		2 000	28.00	$\text{LiOH}$		4 000	104.2	$\text{NaBrO}_3$ , 18°		2 000		18°		
2 000	42.7	3 000	21.55	18°		5 000	86.7	2 000		3 880		2 000		
3 000	33.8	4 000	16.20	2 000	113.3	6 000	68.9	$\frac{1}{2}\text{Na}_2\text{S}$		5 880		3 880		
4 000	26.5	5 000	11.90	3 000	94.4	7 000	54.2	0°		2 000		25°		
$\text{NH}_4\text{CNS}$ , 18°		$\frac{1}{2}\text{Ca}(\text{ClO}_3)_2$		4 000	78.7	8 000	43.0	18°		3 000		$\frac{1}{2}\text{Na}_2\text{CrO}_4$ , 18°		
2 000	84.6	6°		5 000	(65.3)	9 000	33.85	2 000		4 000		2 000		
3 000	79.1	18°		1 955	112.3	10 000	26.3	3 000		5 880		3 000		
4 000	73.9	2 000	32.1	4 535	71.2	11 000	20.5	4 000		2 000		4 000		
$\frac{1}{2}\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$ , 18°		3 000	24.9	50°		12 000	16.3	2 000		3 000		2 000		
2 000	3.85	4 000	19.3	1 933	184.7	13 000	12.9	3 000		4 000		3 000		
3 000	2.52	18°		4 483	127.6	14 000	10.48	4 000		5 880		4 000		
$\frac{1}{2}\text{Zn}(\text{ClO}_3)_2$ , 18°		2 000	49.9	60°		15 000	8.70	2 000		2 000		2 000		
2 000	44.0	3 000	41.0	1 925	206.6	16 000	7.35	3 000		3 000		2 000		
3 000	35.4	4 000	(33.7)	4 465	145.6	17 000	6.37	4 000		4 000		2 000		
4 000	28.7	$\frac{1}{2}\text{Ca}(\text{C}_2\text{H}_3\text{O}_2)_2$ , 18°		$\text{LiClO}_3$ , 18°		18 000	5.60	2 000		5 880		3 000		
$\frac{1}{2}\text{Zn}(\text{BrO}_3)_2$ , 18°		2 000	15.6	2 000		19 000	4.95	3 000		2 000		4 000		
2 000	32.3	3 000	9.40	2 000		4.40	4 000		3 000		2 000		2 000	
3 000	24.2	$\frac{1}{2}\text{Ca}(\text{C}_2\text{H}_3\text{CO}_2)_2$		2 000		50°	5 000		4 000		2 000		2 000	
$\frac{1}{2}\text{Cd}(\text{ClO}_3)_2$ , 18°		18°		2 000		(218.2)	6 000		5 880		2 000		2 000	
2 000	43.6	6°		2 000		184.9	7 000		5 880		3 000		2 000	
3 000	34.6	18°		2 000		158.2	8 000		5 880		4 000		2 000	
4 000	27.3	$\frac{1}{4}\text{Ca}_2\text{Fe}(\text{CN})_6$ , 0°		2 000		133.9	9 000		5 880		5 000		2 000	
$\frac{1}{2}\text{Cu}(\text{ClO}_3)_2$ , 18°		0°		2 000		112.9	10 000		5 880		6 000		2 000	
2 000	43.5	$\frac{1}{2}\text{Sr}(\text{ClO}_3)_2$ , 18°		2 000		94.8	11 000		5 880		7 000		2 000	
3 000	34.5	18°		2 000		80.4	12 000		5 880		9 292		2 000	
$\frac{1}{2}\text{Co}(\text{ClO}_3)_2$ , 18°		6°		2 000		67.9	13 000		5 880		10 690		2 000	
2 000	43.7	18°		2 000		57.5	14 000		5 880				2 000	
3 000	35.1	$\frac{1}{2}\text{Sr}(\text{BrO}_3)_2$ , 18°		2 000		49.2	15 000		5 880				2 000	
4 000	27.9	18°		2 000		42.4	16 000		5 880				2 000	
5 000	21.6	6°		2 000		36.8	17 000		5 880				2 000	
$\frac{1}{2}\text{Ni}(\text{ClO}_3)_2$ , 18°		18°		2 000		32.6	18 000		5 880				2 000	
2 000	43.6	$\frac{1}{2}\text{Sr}(\text{CHO}_2)_2$ , 18°		2 000		29.3	19 000		5 880				2 000	
3 000	34.6	18°		2 000		26.7			5 880				2 000	
4 000	27.5	6°		2 000		24.3			5 880				2 000	
$\frac{1}{3}\text{H}_3\text{BO}_3$ , 18°		18°		2 000		22.2			5 880				2 000	
1 409	0.015	$\frac{1}{2}\text{Sr}(\text{C}_2\text{H}_3\text{O}_2)_2$ , 18°		2 000		20.5			5 880				2 000	
1 777	0.0175	18°		2 000					5 880				2 000	
$\frac{1}{2}\text{Mg}(\text{ClO}_3)_2$ , 18°		6°		2 000					5 880				2 000	
2 000	44.3	18°		2 000					5 880				2 000	
3 000	35.6	$\frac{1}{4}\text{Sr}_2\text{Fe}(\text{CN})_6$ , 0°		2 000					5 880				2 000	
4 000	28.4	0°		2 000					5 880				2 000	
$\frac{1}{2}\text{Mg}(\text{BrO}_3)_2$ , 18°		18°		2 000					5 880				2 000	
2 000	34.0	18°		2 000					5 880				2 000	
3 000	25.6	6°		2 000					5 880				2 000	
$\frac{1}{2}\text{Ba}(\text{ClO}_3)_2$		18°		2 000					5 880				2 000	
C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	C	$10^6\text{K}/\text{C}$	



$\frac{1}{2}\text{K}_2\text{CO}_3$ , 18°		$\text{KC}_2\text{H}_3\text{O}_2$ , 18°		$\frac{1}{3}\text{K}_3\text{Fe}(\text{CN})_6$ , 18°	
C	$10^6\kappa/\text{C}$	C	$10^6\kappa/\text{C}$	C	$10^6\kappa/\text{C}$
2 000	62.3	2 000	51.3	2 000	75.3
3 000	55.2	3 000	41.4		
4 000	48.7	4 000	32.7	$\frac{1}{4}\text{K}_4\text{Fe}(\text{CN})_6$ , 18°	
5 000	42.7	5 000	24.8	2 000	62.5
6 000	37.5	6 000	18.3		
8 200	26.5	7 500	11.22	$\frac{1}{2}\text{K}_2\text{CrO}_4$ , 18°	
11 160	13.14	9 128	5.24	2 000	71.9
$\frac{1}{2}\text{K}_2\text{C}_2\text{O}_4$ , 18°		$\text{KCN}$ , 18°		3 000	59.8
1 293	70.7	1 029	99.7	$\text{RbOH}$ , 18°	
$\frac{1}{2}\text{KHCO}_3$ , 18°		$\text{KCNS}$ , 18°		2 000	168.6
1 032	36.0	2 000	86.7	3 000	148.8
2 132	32.2				

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(For a key to the periodicals see end of volume)

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- (160) Lorenz and Schmidt, 93, 112: 209; 20. (160.5) Lottermoser, 9, 33: 514; 27. (161) Lovén, 7, 17: 374; 95. (162) McBain and Taylor, 25, 43: 321; 10. (163) MacGregory, 8, 51: 126; 94. (163.5) MacInnes and Shedlovski, The Rockefeller Institute for Medical Research, 0. (164) Maynard and Howard, 4, 123: 960; 23. (165) Mazzetti, 36, 54: 891; 24. (166) Melcher, 1, 32: 50; 10. (167) Meldrum, 50, 15: 474; 11. (168) Menzel, 7, 105: 402; 23. (169) Meyer, 93, 118: 1; 21.
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- (180) Noyes, 152, No. 63; 07. (181) Noyes, Boggs, Farrell and Stewart, 1, 33: 1650; 11. (182) Noyes and Coolidge, 152, No. 63: 9; 07. (183) Noyes and Cooper, 152, No. 63: 115; 07. (184) Noyes and Eastman, 152, No. 63: 239; 07. (185) Noyes and Falk, 1, 34: 454; 12. (186) Noyes and Johnston, 1, 31: 987; 09. (187) Noyes and Kato, 152, No. 63: 151; 07. (188) Noyes, Kato and Sosman, 7, 73: 1; 09. (189) Noyes, Kato and Sosman, 1, 32: 159; 10.
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- (230) Rosenheim, Weinberg and Pinsker, 93, 84: 217; 13. (231) Rosenheim and Weinheber, 93, 69: 261; 11. (232) Ruby and Kawai, 1, 48: 1119; 26. (233) Ruer, 93, 43: 282; 05. (234) Ruer and Levin, 93, 46: 449; 05. (235) Sakhanov, 9, 19: 588; 13. (236) Sandonnini, 9, 16: 227; 10. (237) Sand-



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## ELECTRICAL CONDUCTIVITY OF SATURATED SOLUTIONS OF SLIGHTLY SOLUBLE ELECTROLYTES

H. I. SCHLESINGER AND JUDITH E. WALLEN

**Scope.**—Electrolytes with solubilities less than 0.1 equivalent per liter.

**Arrangement.**—Table 1 gives both the conductance and the solubility computed therefrom. Table 2 gives the conductance only. In each part the arrangement is alphabetical with respect to the symbol of the cation, with organic cations at the end.

**Units.**—Conductivities in reciprocal ohms (see p. 230 for cell constant basis); solubilities in equivalents per liter.

**Abbreviations and Symbols.**— $\kappa_w$  = specific conductance of the water used.

$\kappa_s$  = specific conductance of the solution, corrected for  $\kappa_w$  in the case of salts, uncorrected in all other cases.

$S$  = solubility of the electrolyte as computed from the relation  $S = \frac{\kappa'_s \times 10^3}{\alpha \Lambda_0}$ , in which  $\Lambda_0$  is the value assumed for the equivalent

conductance of the completely ionized electrolyte,  $\alpha$  is the value assumed for the "degree of ionization" ( $\Lambda/\Lambda_0$ ) of the electrolyte in the saturated solution, and  $\kappa'_s$  is the value of  $\kappa_s$  after correction (where possible and necessary) for the effects of hydrolysis. No calculation of  $S$  has been attempted in cases where the use of the above relation involves assumptions of doubtful validity.  $S$  has been calculated at round values of the temperature, only where the data justified interpolation.

**Nature of Crystalline Phase.**—Except as otherwise indicated, the crystalline phase was prepared by precipitation methods.

TABLE 1.—ELECTROLYTES FOR WHICH BOTH CONDUCTANCE AND SOLUBILITY ARE GIVEN

Crystalline phase	$t, ^\circ\text{C}$	$\kappa_w \times 10^3$	$\kappa_s \times 10^3$	$\Lambda_0$	$\alpha$	$S \times 10^3$	Lit.
AgCl.....	1.55	0.75	0.297				(9)
	4.68	1.21	.393				
	5.00		.404	84.71	1.0	4.77	
	9.66	1.22	.594	97.02	1.0		
	10.00		.611	97.91	1.0	6.24	
	10.9	1.13	.663	100.29	1.0		
	15.00		.879	111.12	1.0	7.91	
	17.33	1.28	1.067	117.27	1.0		
	17.57	1.21	1.085	117.90	1.0		
	18.00	1.16	1.119	119.04	1.0	9.40	
	18	0.56	1.259	119.04	1.0		(12)
	19.95	1.31	1.329				(1)
	20.00		1.261	124.32	1.0	10.61	(9)
	25.00		1.794	137.53	1.0	13.04	
	25.86	1.21	1.899	139.80	.999		
	33.68	2.03	3.007	160.45	.999		

TABLE 1.—(Continued)

Crystalline phase	$t, ^\circ\text{C}$	$\kappa_w \times 10^3$	$\kappa_s \times 10^3$	$\Lambda_0$	$\alpha$	$S \times 10^3$	Lit.
AgCl.—(Cont'd)....	34.26	1.21	3.188	161.98	0.999		(9)
	50.00	$\leq 0.8$	7.892	217	.998	36.4	(12)
	100.00	$\leq 0.8$	57.840	395.8	.993	146	
	100.00	2.82	56.640	395.8	.993	144	(2)
AgBr.....	19.96	1.23	0.057	126.36	1.0	0.42	(1)
	21.1	1.21	.075	129.42	1.0	0.548	(9)
	100.0	2.30	7.393	400.04	.999	18	(2)
AgBrO <sub>3</sub> .....	19.94	0.93	663.24	105.9	0.954	6 564	(1)
AgI.....	20.8	1.14	0.002	127.45	1.00	0.013	(9)
AgIO <sub>3</sub> .....	9.43	1.05	6.850			97.1	(9)
	10.00		7.031	71.94	0.995	98.3	
	15.00		9.828	81.72	.995	121.0	
	18.00	1.16	11.890	87.58	.995	137.0	
	18.37	1.27	12.160				(1)
	19.95	1.32	14.04				(9)
	20.00		13.55	91.49	.994	149.0	
	25.00		18.20	101.27	.993	181	
	26.60	1.60	20.00				
AgSCN.....	19.96	1.019	0.096	115.3	1.00	0.78	(1)
	100.0	2.43	13.89				(2)
BaSO <sub>4</sub> .....	0.77	0.77	1.125				(9)
	5.00		1.330	85.85	0.995	15.6	
	10.00		1.664	100.14	.995	16.7	
	15.00		2.072	114.43	.995	18.3	
	17.90	1.25	2.389				
	18.00	1.25	2.398	123.0	.994	19.5	
	18.00		2.229	123.0			(12)
	20.00		2.539	128.72	.994	19.8	
	25.00		3.072	143.01	.993	21.6	
	25.00	0.68	2.997	143.01			
	25.00	1.3	2.7	143.01			(4)
	26.75	1.43	3.345				(9)
	50.00	0.8	6.41	229	.99	28.4	(12)
	100.00	.8	13.99	434	.99	32.6	
Barite.....	3.35	1.40	1.453	81.13			(9)
	5.00		1.576	85.84	.995	18.5	
	10.00		1.978	100.13	.994	19.9	
	15.00		2.440	114.43	.994	21.5	
	17.65	1.40	2.706	122.00			
	18.00	1.40	2.747	123.00	.994	22.4	
	20.00		2.951	128.72	.994	23.1	
	25.00		3.517	143.01	.993	24.8	
	33.27	1.40	4.680	166.64			(9)
BaC <sub>2</sub> O <sub>4</sub> ·7H <sub>2</sub> O.....	2.46	2.5	32.09				
	5.00		36.73	80.4	.922	495	
	10.00		47.53	94.2	.917	550	
	15.00		60.39	107.8	.912	614	
	17.38	2.5	68.35				
	18.00	2.5	70.13	116.0	.909	665	
	20.00		74.82	121.5	.907	679	
	25.00		91.62	135.1	.902	752	
	33.73	2.5	127.9				



TABLE 1.—(Continued)

Crystalline phase	<i>t</i> , °C	$\kappa_W \times 10^3$	$\kappa_S \times 10^3$	$\Lambda_0$	$\alpha$	$S \times 10^3$	Lit.
BaC <sub>2</sub> O <sub>4</sub> ·2H <sub>2</sub> O.....	3.0	1.70	32.97				(9)
	5.00		37.50	80.59	0.922	505	
	5.47	1.70	39.16				
	10.00		50.58	94.21	.915	587	
	11.28	1.70	54.84				
	15.00		67.61	107.8	.905	693	
	17.9	1.70	77.92				
	18.0	1.70	78.32	116.0	.902	749	
	20.00		86.10	121.5	.899	788	
	23.3	1.70	101.0				
	25.00		108.6	135.1	.891	902	
	28.4	1.70	126.3				
	2.07	1.37	33.87				(9)
	4.2	1.37	38.48				
	16.15	1.37	83.79				
CaC <sub>2</sub> O <sub>4</sub> ·H <sub>2</sub> O.....	17.85	1.37	94.01				
	18.00	1.37	94.91	116.0	.890	919	
	0.46	1.09	4.296				(9)
	5.00		5.333	77.30	.980	70.3	
	10.00		6.761	90.65	.978	76.18	
	15.00		8.492	103.99	.977	83.4	
	16.4	1.66	8.991				
	18.00	1.86	9.586	112.0	.976	87.3	
	20.00		10.270	117.34	.975	89.5	
	25.00		12.370	130.68	.975	96.9	
MgC <sub>2</sub> O <sub>4</sub> .....	35.8	2.29	17.97				
	18.0		199.3	106	.992	2 045	(9)
PbSO <sub>4</sub> .....	0.37	2.40	16.467				(9)
	3.48	1.12	19.286				
	5.00		20.40	89.9	.950	236	
	10.00		24.70	104.9	.949	236	
	15.00		29.50	120.0	.948	244	
	16.98	2.07	31.369				
	18.00	2.40	32.60	129.0	.947	249	
	20.00		35.00	135.0	.946	255.5	
	25.00		40.30	150.1	.945	268	
	33.23	4.06	47.899				
TiBr.....	0.13	1.76	69.13				(9)
	9.37	1.76	107.89				
	10.00		111.3	109.8	.982	1 030	
	15.00		159.1	124.06	.980	1 310	
	18.00		192.0	132.61	.978	1 480	
	20.00		215.8	138.31	.977	1 600	
	20.06	0.75	220.7	138.48			(1)
	25.00		293.8	152.57	.974	1 980	(9)
	25.68	1.76	305.6				
	19.94	1.10	1 079	117.6	.945	9 720	(1)
TiBrO <sub>3</sub> .....	9.54		940.6				(9)
	10.00		966.1	108.04	.945	9 460	
	15.00		1 283	122.10	.942	11 200	
	17.70		1 487.5				
	18.00		1 513	130.54	.939	12 400	
	19.98	0.9	1 678				(1)
	20.00		1 687	136.17	.938	13 200	(9)
	25.00		2 160	150.23	.934	15 400	
	25.76		2 250.8				
	9.90	1.24	11.908				(9)
TiI.....	10.00		11.99	109.03	.995	111.0	
	15.00		17.68	121.1	.994	147.0	
	18.00	1.24	22.248	131.55	.994	170.0	
	18.08	1.24	22.368				
	20.00		26.12	137.18	.993	191.4	
	20.15		26.154	137.6	.993		(1)
	25.00		36.64	151.26	.992	244.0	(9)
	26.02	1.24	39.391				(9)
	19.95	1.06	154.1	103.23	.978	1 530	(1)
	19.95	1.0	1 399	127	.944	11 700	(1)
TiIO <sub>3</sub> .....	1.35	2.2	24.70				(9)
	5.00		29.38	77.3	.930	408	
	10.00		37.67	90.65	.924	438	
	15.00		47.53	103.99	.922	496	
	15.90	2.2	49.48				
	18.00	2.2	53.95	112.0	.920	523	
	20.00		58.08	117.34	.919	538	
	25.00		70.79	130.68	.914	592	
	31.70	2.2	89.14				
	37.27	2.2	106.1				

TABLE 2.—ELECTROLYTES FOR WHICH THE CONDUCTANCE ONLY IS GIVEN

Crystalline phase	<i>t</i> , °C	$\kappa_W \times 10^3$	$\kappa_S \times 10^3$	Lit.
AgOH.....	19.96	1.22	29.24	(1)
	24.94	1.15	35.944	
	19.46	1.017	6.100	(1)
	19.96	0.87	19.0	(1)
	0.26	1.4	6.664	(9)
	5		8.872	
	10		11.89	
	14.82	1.4	15.594	
	15		15.74	
	17.07	1.4	17.762	
	18.00	1.4	18.581	
	20.00		20.70	
	25.00		26.61	
	30.76	1.4	34.965	
	37.30	1.4	45.954	
Ag <sub>2</sub> CrO <sub>4</sub> .....	75	(?)	160	
	9.72	1.06	16.184	(9)
	10.00		16.48	
	15.00		21.68	
	18.00	1.23	25.475	
	18.50	1.47	26.164	
	20.00		28.31	
	25.00		35.97	
	26.90	2.02	39.391	
	25.0		4 975	(9)
	25	1.0	234.6	(14)
	25	1.0	131.8	(14)
	25	1.0	251.5	(14)
	25.00	1.0	1 924	(9)
	25.00	1.0	583.4	(14)
AgOOCCH <sub>3</sub> .....	25.00	1.0	989	(14)
	25.00	1.0	1 009	(14)
	25.00	1.0	251.7	(14)
	9.50		1 224.4	(9)
	10.00		1 236	
	15.00		1 419	
	17.23		1 500.8	
	18.00		1 528.5	
	20.00		1 607	
	25.00		1 791	
	25.75		1 823.8	
	18.00	1.7	25.475	(9)
	0.88	0.75	1.103	(9)
	5.00		1.503	
BaCO <sub>3</sub> .....	10.00		2.056	
	15.00		2.761	
	16.07	1.40	2.910	
	17.42	1.39	3.118	
	18.00	1.82	3.197	
	20.00		3.508	
	25.00		4.345	
	28.08	1.85	4.923	
	17.47	1.5	39.370	(9)
	18.00	1.5	39.960	
	26.11	1.5	50.550	
	0.05	1.28	19.580	(9)
	5.00		23.44	
	10.00		28.12	
	15.00		33.81	
CaF <sub>2</sub> .....	16.08	1.80	34.740	
	17.28	2.10	36.290	
	18.00	2.14	37.060	
	20.00		39.45	
	25.00		45.81	
	26.59	2.57	48.000	
	40.00	3.1	65.530	
	0.51	1.07	1 096.9	(9)
	5.00		1 274.0	
	9.94	1.07	1 486.5	
	10.00		1 490.0	
	14.56	1.07	1 707.3	
	15.00		1 726.0	
	18.00	1.07	1 878.1	
	18.22	1.07	1 889.1	
CaSO <sub>4</sub> ·2H <sub>2</sub> O (Gypsum).....	19.60		1 978	(7)
	19.60		2 066	(7)
	19.94	1.1	1 964.0	(9)
	20.00		1 972.0	
	25.00	1.33	2 207.8	
Large crystals.....				
Fine powder.....				



TABLE 2.—(Continued)

Crystalline phase	$t, ^\circ\text{C}$	$\kappa_W \times 10^4$	$\kappa_S \times 10^4$	Lit.
CaSO <sub>4</sub> ·2H <sub>2</sub> O (Gypsum) Fine powder.—(Cont'd).....	25.00		2 213.0	(4)
Large crystals.....	40.00		2 890	(7)
Fine powder.....	40.00		3 150	(7)
Large crystals.....	59.95		3 620	(7)
Fine powder.....	59.95		3 761	(7)
Wyoming.....	0		944	(5)
	10		1 485	
	18		1 828	
	25		2 204	
	30		2 243	
	35		2 678	
	40		2 842	
	45		3 042	
	55		3 372	
	65.3		3 600	
CaCO <sub>3</sub> .....	7.9	1.6	20.27	(8)
	9.38	1.6	21.71	
	10.00		22.03	
	15.00		26.17	
	17.34	1.6	28.25	
	18.00		28.84	
	20.00		30.00	
	25.00		35.97	
	25.96	1.6	36.96	
Calcite.....	2.03	1.9	15.27	(8)
	5.00		17.07	
	10.00		20.42	
	15.00		24.54	
	17.44	1.9	26.64	
	18.00		27.29	
	20.00		29.17	
	25.00		33.80	
	30.00		38.30	
	32.2	1.9	41.16	
	34.8	1.9	44.06	(8)
Aragonite.....	3.18	2.2	19.44	
	5.00		20.7	
	10.00		25.1	
	15.00		30.0	
	17.60	2.2	31.72	
	18.00		33.35	
	20.00		35.5	
	25.00		41.0	
	27.9	2.2	43.16	
	30.00		45.4	
	31.1	2.2	46.95	
CdCrO <sub>4</sub> ·3H <sub>2</sub> O.....	11.13	1.3	19.890	(9)
	15.00		24.95	
	18.00	1.3	26.970	
	18.06	1.3	27.110	
	20.00		30.97	
	25.00		36.22	
	26.75	1.3	38.290	
Ce(IO <sub>3</sub> ) <sub>3</sub> ·2H <sub>2</sub> O.....	25	1.0	636.8	(13)
Ce <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> ·10H <sub>2</sub> O.....	25	1.0	0.651	(13)
Ce <sub>2</sub> (C <sub>2</sub> H <sub>4</sub> O <sub>4</sub> ) <sub>3</sub> ·4.5H <sub>2</sub> O.....	25	1.0	51.66	(13)
CuI.....	24.62	2.17	2.128	(8)
CuSCN.....	18	1.2	0.4	(10)
HgCl.....	0.5	1.12	.60	(9)
	18.0	1.7	1.34	
	24.6	2.2	2.13	
	43.0	2.1	6.1	
HgI <sub>2</sub> .....	18		0.2(?)	(9)
La(IO <sub>3</sub> ) <sub>3</sub> ·3H <sub>2</sub> O.....	25	1.4	692.0	(13)
La <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> ·10H <sub>2</sub> O.....	25	1.4	953	(13)
La <sub>2</sub> (C <sub>2</sub> H <sub>4</sub> O <sub>4</sub> ) <sub>3</sub> ·3H <sub>2</sub> O.....	25	1.4	58.5	(13)
Li <sub>2</sub> PO <sub>3</sub> ·3.5H <sub>2</sub> O.....	25	3.2	274	(15)
Li <sub>2</sub> PO <sub>4</sub> ·0.5H <sub>2</sub> O.....	25	3.0	937	(15)
Mg(OH) <sub>2</sub> .....	Conductance varied with time			(3, 10)
MgF <sub>2</sub> .....	3		139.90	(9)
	18		223.80	
	27		270.70	
MgCO <sub>3</sub> .....	8.31		669.5	(8)
	17.78		791.2	
	25.94		885.1	
Mn(OH) <sub>2</sub> .....	18	2.0	9.490	(16)
Nd <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> ·10H <sub>2</sub> O.....	25	1.0	0.764	(13)
Pb(OH) <sub>2</sub> .....	19.96	0.97	25.470	(1)
PbF <sub>2</sub> .....	8.99	1.6	330.70	(9)
	10.00		340.4	

TABLE 2.—(Continued)

Crystalline phase	$t, ^\circ\text{C}$	$\kappa_W \times 10^4$	$\kappa_S \times 10^4$	Lit.
PbF <sub>2</sub> —(Continued).....	15.00		392.6	(9)
	17.63	1.6	426.20	
	18.00	1.6	430.50	
	20.00		453.9	
	25.00		514.0	
	26.61	1.6	534.50	
PbCl <sub>2</sub> .....	19.95		53 540	(1)
PbBr <sub>2</sub> .....	19.96		3 692.0	(1)
Pb(BrO <sub>3</sub> ) <sub>2</sub> .....	19.94		4 630.4	(1)
PbI <sub>2</sub> .....	20.10		338.40	(1)
Pb(IO <sub>3</sub> ) <sub>2</sub> .....	9.17	1.13	3.580	(8)
	10.00		3.750	
	15.00		5.012	
	17.1	1.42	5.670	
	18.00	1.25	5.960	
	19.95	0.98	6.500	(1)
	20.00		6.683	(9)
	25.00		8.750	
	25.77	1.77	9.130	
Pb(SCN) <sub>2</sub> .....	19.96		5 346	(1)
Pb <sub>2</sub> (PO <sub>4</sub> ) <sub>3</sub> .....	19.95	1.207	0.14	(1)
PbCO <sub>3</sub> .....	19.96	1.0	1.390	(1)
PbC <sub>2</sub> O <sub>4</sub> .....	15.77	1.0	1.174	(9)
	18.00	1.2	1.299	
	19.96	1.2	1.519	(1)
	22.00	1.2	1.54	(9)
Pr <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> ·10H <sub>2</sub> O.....	25	1.0	1.164	(13)
Sa <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> .....	25	1.0	0.82	(13)
SrF <sub>2</sub> .....	0.26	2.2	101.210	(9)
	5.00		117.5	
	10.00		136.5	
	15.00		157.8	
	17.38	2.2	169.040	
	18.00	2.2	171.83	
	20.00		180.3	
	25.00		204.6	
	27.39	2.2	216.790	
SrSO <sub>4</sub> .....	2.85	2.51	84.65	(9)
	5.00		90.78	
	10.00		104.50	
	10.18	2.51	104.80	
	15.00		118.30	
	17.38	2.51	125.09	
	18.00		126.9	
	20.00		132.6	
	25.00		147.40	
	32.26	2.51	170.78	
Celestite.....	3.27	2.20	85.89	(9)
	5.00		90.78	
	10.00		104.5	
	15.00		118.30	
	17.69	2.19	125.98	
	18.00	2.19	126.87	
	20.00		132.600	
	25.00		147.400	
	32.50	2.19	172.37	
Tl <sub>2</sub> S.....	19.96	0.8	216	(1)
Tl <sub>2</sub> C <sub>2</sub> O <sub>4</sub> .....	19.96		5 341	(1)
Y <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> ·9H <sub>2</sub> O.....	25	1.0	1.740	(13)
Yb <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> ·10H <sub>2</sub> O.....	25	1.0	4.849	(13)
ZnCrO <sub>4</sub> ·2H <sub>2</sub> O.....	9.76	0.98	5.803	(9)
	10.00		5.821	
	15.00		7.112	
	17.92	1.23	7.963	
	18.00	1.20	7.992	
	20.00		8.660	
	25.00		10.210	(9)
	26.15	1.56	10.578	
Antipyrine salicylate.....	18.0	1.5	1 000	(11)

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Böttger, 7, 46: 521; 03. (2) Böttger, 7, 56: 83; 06. (3) Gjaldback, 83, 144: 145; 25. (4) Hulett, 7, 37: 385; 01. (5) Hulett and Allen, 1, 94: 667; 02. (6) Jaques, 83, 5: 225; 10. (7) Jones and Partington, 4, 107: 1019; 15. (8) Kohlrausch, 7, 44: 197; 03. (9) Kohlrausch, 7, 64: 129; 08. (10) Kohlrausch and Rose, 7, 12: 234; 93. (11) Kolthoff, 70, 41: 135; 22. (12) Melcher, 1, 32: 50; 10. (13) Rimbaud and Schubert, 7, 67: 183; 09. (14) Romann, Thesis, Nancy, 1913. (15) Rosenheim and Reglin, 93, 120: 103; 22. (16) Sackur and Fritsmann, 9, 15: 842; 09.



## ELECTRICAL CONDUCTIVITY AND IONIZATION CONSTANTS OF WEAK ELECTROLYTES IN AQUEOUS SOLUTION\*

JAMES KENDALL

## ABBREVIATIONS AND SYMBOLS

Conc. range. The range of concentrations ( $c$ ) covered by the experimental data.

$\Lambda_c$  (resp.  $\Lambda_0$ ) The equivalent conductance of the electrolyte at the concentration  $c$  (resp. zero). The  $\Lambda_0$  values were obtained by adding to the  $\Lambda_c$  value for  $H^+$  (resp.  $OH^-$ ) a  $\Lambda_0$  value for the anion (resp. cation) of the electrolyte estimated usually from the number of carbon atoms by the Ostwald method.

$$k = \frac{\Lambda_c^3}{\Lambda_0(\Lambda_0 - \Lambda_c)} \quad (1)$$

In computing  $k$ , the water correction has been applied only in the case of acids weaker than acetic, *v.* (311). Where no constant value is obtained for  $k$ , a value for  $\Lambda_c$  is given in its stead.

[ ] Brackets surrounding a value of  $k$  indicate that it varies considerably within the concentration range given. Brackets surrounding a  $\Lambda$  value indicate "approximate."

## ABRÉVIATIONS ET SYMBOLES

Conc. range. L'intervalle des concentrations ( $c$ ) couvert par les données expérimentales.

$\Lambda_c$  (resp.  $\Lambda_0$ ) La conductibilité équivalente de l'électrolyte à la concentration  $c$  (resp. zéro). Les valeurs de  $\Lambda_0$  ont été obtenues en ajoutant à la valeur  $\Lambda_c$  de  $H^+$  (resp.  $OH^-$ ) la valeur  $\Lambda_0$  de l'anion (resp. du cation) de l'électrolyte, cette valeur étant généralement calculée par la méthode d'Ostwald à partir du nombre d'atomes de carbone.

$$k = \frac{\Lambda_c^3}{\Lambda_0(\Lambda_0 - \Lambda_c)} \quad (1)$$

Pour le calcul de  $k$ , la correction pour l'eau n'a été faite que dans le cas d'acides plus faibles que l'acétique, *v.* (311). Lorsque la valeur obtenue pour  $k$  n'est pas constante, il a été donné à sa place une valeur de  $\Lambda_c$ .

[ ] Des crochets entourant une valeur de  $k$  indiquent que celle-ci varie considérablement dans l'intervalle de concentration donné. Des crochets entourant une valeur de  $\Lambda$  indiquent "approximatif."

## ABKÜRZUNGEN UND SYMBOLE

Conc. range. Experimentell bestimmter Konzentrations ( $c$ ) Bereich.

$\Lambda_c$  (bezw.  $\Lambda_0$ ) Die äquivalente Leitfähigkeit bei der Konzentration  $c$  des Elektrolyten (bezw. bei der Konzentration Null). Die Werte von  $\Lambda_0$  sind erhalten durch Addition von  $\Lambda_c$  für  $H^+$  (bezw.  $OH^-$ ) zu dem Wert  $\Lambda_0$  für das Anion (bezw. Kation) des Elektrolyten, welcher Wert gewöhnlich entsprechend der Zahl der Kohlenstoffatome nach der Methode von Ostwald geschätzt ist.

$$k = \frac{\Lambda_c^3}{\Lambda_0(\Lambda_0 - \Lambda_c)} \quad (1)$$

Bei der Berechnung von  $k$  ist die Wasserkorrektur nur bei Säuren die schwächer als Essigsäure sind, angebracht worden, *v.* (311). In dem Falle, wo keine Konstante erhalten wird, steht an dieser Stelle der Wert von  $\Lambda_c$ .

[ ] Ein in Klammern gesetzter Wert von  $k$  zeigt an, dass dieser innerhalb des betrachteten Konzentrationsbereiches sich deutlich ändert. Ein in Klammern gesetzter  $\Lambda$ -Wert bedeutet: "ungefähr" dieser Wert.

## ABBREVIAZIONI E SIMBOLI

Conc. range. Il campo di concentrazione ( $c$ ) abbracciato dai dati sperimentali.

$\Lambda_c$  (resp.  $\Lambda_0$ ) La conducibilità equivalente dell'elettrolita alla concentrazione  $c$  (resp. zero). I valori di  $\Lambda_0$  furono ottenuti aggiungendo al valore di  $\Lambda_c$  per  $H^+$  (resp.  $OH^-$ ) un valore  $\Lambda_0$  per l'anione (resp. catione) dell'elettrolita calcolato generalmente dal numero degli atomi di carbonio col metodo di Ostwald.

$$k = \frac{\Lambda_c^3}{\Lambda_0(\Lambda_0 - \Lambda_c)} \quad (1)$$

Nel calcolare  $k$ , la correzione per l'acqua è stata applicata solo nel caso degli acidi più deboli dell'acido acetico, *v.* (311). Se per  $k$  non si trova un valore costante viene dato invece un valore per  $\Lambda_c$ .

[ ] Quando un valore di  $k$  è compreso fra parentesi significa che esso varia considerevolmente nell'intervallo di concentrazioni indicate. Se un valore di  $\Lambda$  è compreso fra parentesi significa che esso è approssimato.

$\Lambda_0$ values for $H^+$ and $OH^-$					
Temp., °C	$H^+$	$OH^-$	Temp., °C	$H^+$	$OH^-$
0	229.0	118	25	350.0	196
10	275.6	149	35	399.6	228
15	300.4	164.5	40	421.4	244
18	315.2	174	50	464.3	276

\* For more detailed data previous to 1910, see Souder, "The Electrical Conductivity and Ionization Constants of Organic Compounds," New York, Van Nostrand, 1914.



## INORGANIC COMPOUNDS

Electrolyte	$t, ^\circ\text{C}$	Conc. range, $c = \text{formula}$ weight per liter	$\Lambda_0$	$k(\text{or } \Lambda_c)$	Lit.
$\text{H}_2\text{O}$	v. p. 152				
$\text{H}_2\text{O}_2$	25	9.7-6.1	395	$< 5 \times 10^{-12}$	(301)
$\text{HF}$	0	1.0-0.001	251	$9 \times 10^{-4}$	(153)
	25	1.0-0.001	404	$6.9 \times 10^{-4}$	(5, 152, 266, 432, 454, 480)
	18-40	16.0-0.002			(11, 266); cf. (311)
$\text{H}_2\text{S}$	18	0.04-0.004	378	$5.7 \times 10^{-3}$	(589)
				$9.1 \times 10^{-3}$	(16)
$\text{H}_2\text{SO}_4$	25	0.05-0.001	421	$1.7 \times 10^{-3}$	(39, 295, 316, 432)
$\text{H}_2\text{Se}$	25	0.1-0.008	420	$1.90 \times 10^{-4}$	(108, 271)
$\text{H}_2\text{Te}$	18	0.09-0.003	378	$2.27 \times 10^{-3}$	(108, 271)
$\text{H}_2\text{TeO}_6$	25	0.06-0.001	(?)	$\Lambda_{0.03} = 0.98$	(218, 258, 483)
$\text{N}_2\text{H}_4$ , Hydrazine	25	0.12-0.004	257	$2.2 \times 10^{-3}$	(104)
$\text{HN}_3$	0	0.05-0.004	266	$7 \times 10^{-3}$	(429)
				$1 \times 10^{-3}$	(226)
	5	0.05-0.012	293	$8 \times 10^{-3}$	(429)
	10	0.05-0.012	322	$9 \times 10^{-3}$	(429)
	15	0.05-0.012	352	$1.1 \times 10^{-3}$	(429)
	20	0.05-0.012	382	$1.2 \times 10^{-3}$	(429)
	25	0.1-0.001	412	$1.9 \times 10^{-3}$	(226, 606)
$\text{HNO}_3$	0	0.16-0.007	(?)	$\Lambda_{0.04} = 2.4$	(467); cf. (242)
$\text{HNO}_2$	0	0.03-0.001	258	$6.0 \times 10^{-4}$	(469)
	25	0.002-0.0006	412	$4.6 \times 10^{-4}$	(512)
$\text{H}_2\text{NO}$ , Hydroxylamine	18	0.05-0.002	(?)	$\Lambda_{0.05} = 0.4$	(373); cf. (485, 622)
$\text{NH}_4\text{OH}$	0	0.1-0.04	157	$1.39 \times 10^{-3}$	(308)
	10	0.06	202	$1.63 \times 10^{-3}$	(363)
	15	0.1-0.04	225	$1.70 \times 10^{-3}$	(363)
	18	0.1-0.001	238	$1.72 \times 10^{-3}$	(305, 362, 421)
	25	0.1-0.04	271	$1.81 \times 10^{-3}$	(118, 308, 363, 421)
	40	0.1-0.046	342	$1.98 \times 10^{-3}$	(363)
	50	0.1-0.06	404	$1.81 \times 10^{-3}$	(363, 421)
	75	0.1	525	$1.64 \times 10^{-3}$	(421)
	100	0.1-0.01	646	$1.35 \times 10^{-3}$	(421)
	156	0.1-0.01	907	$6.28 \times 10^{-3}$	(421)
	218	0.1-0.01	1140	$1.80 \times 10^{-3}$	(421)
	306	0.1-0.01	1404	$9.3 \times 10^{-3}$	(421)
	0-50				(46, 104, 206, 251, 321, 326, 433); cf. (308)
$\text{H}_2\text{NO}_2\text{S}$ , Aminosulfonic acid	25	0.03-0.001	399	$\Lambda_{0.03} = 315$	(497, 622)
$\text{H}_2\text{N}_2\text{O}_2$ , Nitroamine	0	0.5-0.016	(?)	$\Lambda_{0.07} = 0.75$	(40, 242)
$\text{H}_2\text{N}_2\text{O}_3\text{S}$ , Trisulfimide	25	0.015-0.0005	(?)	$\Lambda_{0.015} = 705$	(239)
$\text{H}_3\text{PO}_4$	25	0.06-0.0009	(?)	$\Lambda_{0.03} = 200$	(481)
$\text{H}_3\text{PO}_3$	25	0.50-0.03	392.5	$\Lambda_{0.04} = 244$	(466)
	18-52	0.5-0.0002			(11, 432)
$\text{H}_3\text{PO}_2$	25	0.5-0.0002	(?)	$\Lambda_{0.03} = 243$	(432)
$\text{H}_3\text{PO}_1$	18	0.1-0.002	340	$\Lambda_{0.01} = 203$	(421)
	15-156	0.5-0.0002			(11, 199, 326, 421, 432); cf. (4, 312, 489)
$\text{H}_4\text{P}_2\text{O}_7$	18	0.05-0.00125	336	$\Lambda_{0.025} = 384$	(4)
$\text{H}_3\text{AsO}_3$	25	0.06-0.001	388	$2.1 \times 10^{-3}$	(627); cf. (62, 101)
$\text{H}_3\text{AsO}_4$	25	0.12-0.001	386	$4.5 \times 10^{-3}$	(368, 575, 596)
$\text{AgOH}$	25	0.0006-0.00007	255	$9 \times 10^{-3}$	(339)
$\text{OsO}_4$	25	0.04	(?)	$\Lambda_{0.04} = 0.15$	(274)
$\text{H}_2\text{BO}_3$	18	0.09-0.02	348	$< 1.7 \times 10^{-3}$	(589)
		1.8-0.38			(63)



## ORGANIC COMPOUNDS

C-Table.—The C-Arrangement; v. Vol. III, p. viii

Electrolyte		t, °C	Conc. range, formula weight per liter	$\Lambda_0$	k(or $\Lambda_c$ )	Lit
Formula	Name					
CHBrN <sub>2</sub> O <sub>4</sub>	Dinitrobromomethane.....	0	0.016-0.004	251	$1.7 \times 10^{-4}$	(254, 259)
CHN.....	Hydrocyanic acid.....	18	0.5-0.06	379	$1.32 \times 10^{-9}$	(589)
		25	0.25-0.013	(?)	$[\Lambda_{0.03} < 0.5]$	(246, 432, 622)
CHNO	Cyanic acid.....	0	0.01-0.002	259	$1.5 \times 10^{-4}$	(417)
CHNS	Thiocyanic acid.....	25	0.5-0.0002	(?)	$\Lambda_{0.03} = 358$	(372, 432)
CHN <sub>3</sub> O <sub>4</sub>	Trinitromethane.....	0	0.016-0.002	251	$\Lambda_{0.016} = 234$	(247); cf. (256)
		25	0.03-0.002	395	$\Lambda_{0.016} = 360$	(247); cf. (256)
CH <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Dinitromethane.....	0	0.016-0.002	251	$1.5 \times 10^{-4}$	(225)
		25	0.016-0.002	392	$2.6 \times 10^{-4}$	(225)
CH <sub>2</sub> N <sub>4</sub>	Tetrazole.....	25	0.03-0.008	400	$1.28 \times 10^{-5}$	(427)
		0-35	0.03-0.001			(42, 427, 428, 551)
CH <sub>2</sub> O	Formaldehyde.....	25	0.03-0.0016	(?)	$\Lambda_{0.03} = 2.4$	(315)
CH <sub>2</sub> O <sub>2</sub>	Formic acid.....	18	0.25-0.001	362	$2.0 \times 10^{-4}$	(17)
		25	0.12-0.001	404	$2.1 \times 10^{-4}$	(436)
		10-54.3	1.0-0.0001			(12, 45, 273, 293, 437)
CH <sub>2</sub> O <sub>3</sub>	Carbonic acid.....	0	0.04-0.006	254	$2.43 \times 10^{-7}$	(310)
		18	0.03-0.01	355.7	$3.09 \times 10^{-7}$	(310)
		25	0.03-0.007	396.6	$3.44 \times 10^{-7}$	(310)
		0-40	0.4-0.003			(325, 452, 589, 613)
CH <sub>3</sub> NO	Formamide.....	19	0.4-0.06	(?)	$\Lambda_{0.06} = 0.06$	(574)
CH <sub>3</sub> NO <sub>2</sub>	Formhydroxamic acid.....	25	0.06-0.016	393	$1 \times 10^{-7}$	(426)
CH <sub>3</sub> NO <sub>2</sub>	Nitromethane.....	25	0.24-0.10	393	$1.0 \times 10^{-11}$	(232)
CH <sub>3</sub> N <sub>2</sub> O <sub>2</sub>	Nitrourea.....	0	0.03-0.002	251	$3.9 \times 10^{-5}$	(43)
		10-40	0.03-0.002			(43)
CH <sub>3</sub> N <sub>4</sub>	5-Amino-1, 2, 3, 4-tetrazole.....	0	0.05-0.003	251	$3.4 \times 10^{-7}$	(43)
		10	0.05-0.003	305	$4.5 \times 10^{-7}$	(43)
		20	0.05-0.003	364	$6.2 \times 10^{-7}$	(43)
		25	0.06-0.005	394	$6.8 \times 10^{-7}$	(42, 43)
		30	0.05-0.003	424	$8.0 \times 10^{-7}$	(43)
		40	0.05-0.003	481	$9.9 \times 10^{-7}$	(43)
CH <sub>3</sub> N <sub>2</sub> O	Urea.....	25	2.0-0.004	(?)	$[\Lambda_{0.03} = 0.07]$	(85, 557)
CH <sub>3</sub> N <sub>2</sub> O <sub>2</sub>	Methylnitroamine.....	0	0.016-0.002	246	$2.6 \times 10^{-5}$	(226)
		25	0.03-0.002	383	$7.0 \times 10^{-5}$	(226, 256)
		40	0.016-0.002	466	$5.0 \times 10^{-5}$	(226)
CH <sub>3</sub> N <sub>2</sub> S	Thiourea.....	25	0.03-0.004	(?)	$\Lambda_{0.03} = 0.07$	(557)
CH <sub>3</sub> O <sub>2</sub> S	Formaldehyde sulfurous acid.....	25	0.03-0.0016	(?)	$\Lambda_{0.03} = 360$	(315)
CH <sub>3</sub> O <sub>2</sub> S	Monomethyl sulfate.....	25	0.03-0.001	(?)	$\Lambda_{0.03} = 368$	(434)
CH <sub>3</sub> AsO <sub>2</sub>	Methylarsonic acid.....	0	0.06-0.001	245	$4.3 \times 10^{-7}$	(628)
		25	0.06-0.001	382	$4.1 \times 10^{-7}$	(628)
CH <sub>3</sub> N	Methylamine.....	25	0.12-0.002	258	$4.0 \times 10^{-4}$	(104, 110)
CH <sub>3</sub> N <sub>3</sub>	Guanidine.....	25	0.06-0.004	249	$\Lambda_{0.06} = 190$	(433)
CH <sub>3</sub> N <sub>2</sub> O	Diazoguanidine.....	25	0.03	(?)	$\Lambda_{0.03} = 21.1$	(253)
C <sub>2</sub> HBrClFO <sub>2</sub>	Chlorobromofluoroacetic acid.....	25	0.03-0.001	385	$\Lambda_{0.03} = 335$	(548)
C <sub>2</sub> HBr <sub>2</sub> ClO <sub>2</sub>	Chlorodibromoacetic acid.....	25	0.03-0.001	385	$\Lambda_{0.03} = 340$	(548)
C <sub>2</sub> HBr <sub>2</sub> FO <sub>2</sub>	Dibromofluoroacetic acid.....	25	0.03-0.001	387	$\Lambda_{0.03} = 360.5$	(542)
C <sub>2</sub> HBr <sub>3</sub> O <sub>2</sub>	Tribromoacetic acid.....	25.2	0.03-0.004	385	$\Lambda_{0.03} = 343$	(542)
C <sub>2</sub> HClF <sub>2</sub> O <sub>2</sub>	Chlorodifluoroacetic acid.....	25	0.03-0.004	387	$\Lambda_{0.03} = 380$	(549)
C <sub>2</sub> HCl <sub>2</sub> FO <sub>2</sub>	Dichlorofluoroacetic acid.....	24.7	0.03-0.001	385	$\Lambda_{0.03} = 355$	(547)
C <sub>2</sub> HCl <sub>3</sub> O <sub>2</sub>	Trichloroacetic acid.....	0	3.0-0.002	248	$\Lambda_{0.03} = 220$	(163, 625)
		12.5	1.0-0.016	314	$\Lambda_{0.03} = 291$	(221)
		18	0.13-0.004	346	$\Lambda_{0.03} = 320$	(162)
		25	1.0-0.001	387	$\Lambda_{0.03} = 346$	(109, 145, 313, 436, 625)
		0-60	1.0-0.0005			(299, 474, 607, 610)
C <sub>2</sub> H <sub>2</sub> Cl <sub>2</sub> O <sub>2</sub>	Dichloroacetic acid.....	0	0.03-0.002	249	$\Lambda_{0.03} = 186$	(625)
		12.5	5.0-0.0008	315	$\Lambda_{0.016} = 259$	(221)
		18	1.0-0.001	347	$\Lambda_{0.02} = 275$	(162, 510)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Lambda_0$	<i>k</i> (or $\Lambda_c$ )	Lit.
Formula	Name					
$C_2H_2Cl_2O_2$	Dichloroacetic acid.—(Cont'd)....	25	1.0–0.001	388.5	$\Lambda_{0.01} = 273$	(109, 313, 436, 625)
		0–65	0.5–0.0005			(172, 327, 384, 450, 526)
$C_2H_2F_2O_2$	Diffuoroacetic acid.....	25	0.03–0.001	389	$\Lambda_{0.01} = 302.5$	(544)
$C_2H_2N_4$	Bistetrazole.....	0	0.03–0.008	(?)	$\Lambda_{0.01} = 126.4$	(427)
		12–31	0.03–0.008			(427)
$C_2H_2O_4$	Oxalic acid.....	25	0.03–0.0005	392	$\Lambda_{0.01} = 285$	(131, 404, 436)
		0–65	1.0–0.00001			(45, 48, 123, 126, 149, 198, 300, 326, 352, 354, 554)
$C_2H_3BrO_2$	Bromoacetic acid.....	18	0.3–0.001	350	$1.43 \times 10^{-3}$	(162)
		25	0.03–0.001	389	$1.35 \times 10^{-3}$	(436)
		0	0.03–0.002			(328)
$C_2H_3ClO_2$	Chloroacetic acid.....	14.1	0.05–0.0005	332	$1.58 \times 10^{-3}$	(273)
		25	0.06–0.001	389	$1.52 \times 10^{-3}$	(109, 146, 384, 436)
		0–52	1.0–0.002			(11, 118, 153, 328)
$C_2H_3Cl_2O_2$	Chloral hydrate.....	0.65	0.01	(?)	$\Lambda_{0.01} = 0.6$	(167)
$C_2H_3FO_2$	Fluoroacetic acid.....	25	0.03–0.001	390	$2.1 \times 10^{-3}$	(541)
$C_2H_3IO_2$	Iodoacetic acid.....	25	0.03–0.001	389	$7.1 \times 10^{-4}$	(579)
$C_2H_3N$	Acetonitrile.....	0	0.03	(?)	$\Lambda_{0.01} = 0.19$	(209)
$C_2H_3NO_2$	Oxamic acid.....	25	0.03–0.001	388	$7.7 \times 10^{-3}$	(436)
$C_2H_3NO_2$	Oximinoacetic acid.....	25	0.12–0.001	390	$9.7 \times 10^{-4}$	(244, 291)
$C_2H_3N_2O_2$	Triazoacetic acid.....	25	0.07–0.003	390	$9.4 \times 10^{-4}$	(453)
$C_2H_3N_4O$	Tetrazole amide.....	20	0.03–0.008	369	$3.3 \times 10^{-3}$	(427)
		0–35	0.03–0.008			(427)
$C_2H_4BrNO$	N-Bromoacetamide.....	0	0.03	(?)	$[\Lambda_{0.01} = 0.2]$	(237)
		25	0.06	(?)	$[\Lambda_{0.01} = 0.15]$	(237)
$C_2H_4ClNO$	N-Chloroacetamide.....	25	0.03	(?)	$[\Lambda_{0.01} = 0.5]$	(237)
$C_2H_4F_2N_2O_2$	Diffuoroethylnitroamine.....	25	0.03–0.001	386	$1.34 \times 10^{-3}$	(545)
$C_2H_4F_2O$	Diffuoroethyl alcohol.....	25	0.5	(?)	$\Lambda_{0.1} = 0.02$	(543)
$C_2H_4N_2O_2$	Hydraziacetic acid.....	25	0.03	(?)	$\Lambda_{0.01} = 78$	(243)
$C_2H_4N_2O_2$	Ethylnitrolic acid.....	0	0.03	248	$5 \times 10^{-3}$ (?)	(235); cf. (209)
$C_2H_4N_2O_4$	Dinitroethane.....	0	0.016–0.004	249	$2.2 \times 10^{-3}$	(259)
		25	0.03–0.008	392	$5.6 \times 10^{-6}$	(342)
$C_2H_4N_2O_4$	Oxaldihydroxamic acid.....	25	0.03–0.008	389	$1.7 \times 10^{-7}$	(426)
$C_2H_4O$	Acetaldehyde.....	25	0.08–0.001	(?)	$\Lambda_{0.01} = 4.7$	(315)
$C_2H_4OS$	Thioacetic acid.....	25	0.06–0.001	392	$4.60 \times 10^{-4}$	(436)
$C_2H_4O_2$	Acetic acid.....	18	0.08–0.001	350.2	$1.806 \times 10^{-3}$	(383, 421, 619)
		25	0.06–0.0005	390.8	$1.813 \times 10^{-3}$	(109, 308, 311, 475, 560)
		100	0.08–0.01	772	$1.1 \times 10^{-3}$	(421)
		156	0.08–0.01	979	$5.3 \times 10^{-3}$	(421)
		218	0.08–0.01	1163	$1.7 \times 10^{-3}$	(421)
		306	0.08–0.01	1266	$1.4 \times 10^{-7}$	(421)
		0–52	5.0–0.0005			(11, 35, 37, 40, 124, 149, 293, 321, 326, 363, 376, 435, 436, 437, 491, 500, 609); cf. (595)
$C_2H_4O_2S$	Thioglycolic acid.....	25	0.01–0.0004	387	$2.85 \times 10^{-4}$	(322); cf. (436)
$C_2H_4O_2$	Glycolic acid.....	25	0.25–0.001	390	$1.49 \times 10^{-4}$	(79, 436)
		17–25	0.12–0.001			(35, 45, 377)
$C_2H_4O_4$	Glyoxylic acid.....	25	0.06–0.001	388	$4.6 \times 10^{-4}$	(436)
$C_2H_4F_2N$	Diffuoroethylamine.....	25	0.03–0.008	245	$3.3 \times 10^{-7}$	(545)
$C_2H_4NO$	Acetamide.....	15	0.5–0.016	(?)	$\Lambda_{0.01} = 0.63$	(554)
		25	0.03	(?)	$\Lambda_{0.01} = 0.95$	(553)
$C_2H_4NO_2$	Acethydroxamic acid.....	25	0.07–0.02	390	$2.7 \times 10^{-3}$	(426)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	$\Lambda_0$	k(or $\Lambda_c$ )	Lit.
Formula	Name					
C <sub>2</sub> H <sub>5</sub> NO <sub>2</sub>	Aminoacetic acid.....	18	0.1	(?)	$\Lambda_{0.1} = 0.035$	(331); cf. (45)
		25	1.0–0.016	(?)	$\Lambda_{0.06} = 0.05$	(85, 197); cf. (44, 516)
C <sub>2</sub> H <sub>5</sub> NO <sub>2</sub>	Isonitroethane.....	0	0.02	(?)	$\Lambda_{0.02} = 10.0$	(254)
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	Biuret.....	25	0.1	(?)	$\Lambda_{0.1} = 0.35$	(85)
C <sub>2</sub> H <sub>5</sub> HgO	Mercury ethyl hydroxide.....	25	0.06–0.004	(?)	$\Lambda_{0.016} = 1.7$	(144); cf. (104)
C <sub>2</sub> H <sub>5</sub> N <sub>2</sub> O	Nitrosodimethylamine.....	19	0.067	(?)	$\Lambda_{0.067} = 0.41$	(574)
C <sub>2</sub> H <sub>5</sub> N <sub>2</sub> O	O-Methylisourea.....	25	0.03–0.001	240	$6.2 \times 10^{-5}$	(107)
C <sub>2</sub> H <sub>5</sub> O	Ethyl alcohol.....	15, 18	All concns. from pure water to 100% alcohol	(?)	$\Delta$ extremely small at all concns.	(160)
C <sub>2</sub> H <sub>6</sub> O <sub>2</sub>	Glycol.....	25	4–0.03	(?)	$\Lambda_{0.5} = 0.003$	(77, 82)
C <sub>2</sub> H <sub>6</sub> O <sub>2</sub> S	Acetaldehyde sulfurous acid.....	25	0.04–0.01	382	$\Lambda_{0.04} = 332$	(315)
C <sub>2</sub> H <sub>6</sub> O <sub>4</sub> S	Monoethyl sulfate.....	25	0.03–0.001	(?)	$\Lambda_{0.03} = 363$	(434)
C <sub>2</sub> H <sub>7</sub> AsO <sub>2</sub>	Cacodylic acid.....	0	0.06–0.001	248	$4.1 \times 10^{-7}$	(628)
		25	0.12–0.001	381	$4.1 \times 10^{-7}$	(628)
					$6.4 \times 10^{-7}$	(296)
C <sub>2</sub> H <sub>7</sub> N	Dimethylamine.....	25	0.06–0.001	248.5	$5.0 \times 10^{-4}$	(110); cf. (104)
		0–50	0.06			(251)
C <sub>2</sub> H <sub>7</sub> N	Ethylamine.....	25	0.12–0.004	246	$4.6 \times 10^{-4}$	(104)
C <sub>2</sub> H <sub>7</sub> NO <sub>2</sub> S	Ethylsulfonamide.....	25	0.03–0.001	(?)	$\Lambda_{0.03} = 5.0$	(504)
C <sub>2</sub> H <sub>7</sub> OTl	Thallium dimethyl hydroxide.....	25	0.12–0.008	(?)	$\Lambda_{0.12} = 132$	(509)
C <sub>2</sub> H <sub>7</sub> O <sub>4</sub> P	Dimethyl phosphate.....	25	0.125–0.001	386	$\Lambda_{0.03} = 317$	(164)
C <sub>2</sub> H <sub>7</sub> O <sub>4</sub> P	Monoethyl phosphate.....	25	0.125–0.002	386	$\Lambda_{0.125} = 156$	(120)
C <sub>2</sub> H <sub>7</sub> O <sub>4</sub> P	Monoglycol phosphate.....	25	0.125–0.002	386	$\Lambda_{0.125} = 193$	(120)
C <sub>2</sub> H <sub>8</sub> N <sub>2</sub>	Ethylenediamine.....	25	0.06–0.004	242	$7.1 \times 10^{-5}$	(104)
C <sub>2</sub> HCl <sub>3</sub> O <sub>2</sub>	Trichloroacrylic acid.....	25	0.03–0.004	382	$\Lambda_{0.03} = 272$	(72)
C <sub>2</sub> H <sub>2</sub> N <sub>2</sub>	Malononitrile.....	25	0.016	(?)	$\Lambda_{0.016} = 0.40$	(213)
C <sub>2</sub> H <sub>2</sub> N <sub>2</sub> O <sub>2</sub> S	Thioparabanic acid.....	25	0.016–0.001	(?)	$\Lambda_{0.016} = 2.5$	(557)
C <sub>2</sub> H <sub>2</sub> N <sub>2</sub> O <sub>2</sub>	Parabanic acid.....	25	0.03	390	$7.5 \times 10^{-7}$	(624)
C <sub>2</sub> H <sub>2</sub> N <sub>2</sub> O <sub>2</sub>	Cyanonitrosoacetic acid.....	25	0.06–0.002	389	$1.35 \times 10^{-2}$	(244)
C <sub>2</sub> H <sub>2</sub> ClO <sub>4</sub>	Chloromalonic acid.....	25	0.03–0.004	384	$3.6 \times 10^{-2}$	(577)
C <sub>2</sub> H <sub>2</sub> Cl <sub>3</sub> O <sub>2</sub>	Trichlorolactic acid.....	25	0.03–0.001	383	$4.5 \times 10^{-3}$	(378, 436)
		18	0.025–0.013			(419)
C <sub>2</sub> H <sub>3</sub> NO <sub>2</sub>	Cyanoacetic acid.....	25	0.03–0.0002	389.0	$3.65 \times 10^{-3}$	(109, 313, 436, 466)
		0–35	1.0–0.0005			(102.1, 109, 313, 466, 610, 611)
C <sub>2</sub> H <sub>3</sub> NO <sub>2</sub> S	2, 5-Diketotetrahydrothiazole.....	0	0.25–0.06	249	$7.0 \times 10^{-8}$	(305)
		18	0.25–0.06	345	$1.49 \times 10^{-7}$	(305)
		25	0.25–0.03	387	$1.84 \times 10^{-7}$	(305)
					$2.4 \times 10^{-7}$	(436)
C <sub>2</sub> H <sub>3</sub> NO <sub>2</sub> S	Thiocyanoacetic acid.....	25	0.03–0.001	389	$2.60 \times 10^{-3}$	(436)
C <sub>2</sub> H <sub>3</sub> N <sub>3</sub> O <sub>2</sub> S	Isonitrosothiohydantoin.....	25	0.002–0.001	385	$5 \times 10^{-8}$	(235)
C <sub>2</sub> H <sub>3</sub> N <sub>3</sub> O <sub>2</sub>	Cyanuric acid.....	25	0.008–0.001	383	$1.8 \times 10^{-7}$	(231)
					$3.7 \times 10^{-7}$	(26)
		0–96.2	0.03–0.0005			(231, 456, 610)
C <sub>2</sub> H <sub>4</sub> Br <sub>2</sub> O <sub>2</sub>	$\alpha$ , $\alpha$ -Dibromopropionic acid.....	25	0.03–0.001	381	$3.0 \times 10^{-2}$	(579)
C <sub>2</sub> H <sub>4</sub> Br <sub>2</sub> O <sub>2</sub>	$\alpha$ , $\beta$ -Dibromopropionic acid.....	25	0.03–0.001	381	$6.3 \times 10^{-3}$	(579)
C <sub>2</sub> H <sub>4</sub> N <sub>2</sub>	Glyoxaline.....	25	0.06–0.004	247	$1.1 \times 10^{-7}$	(148)
C <sub>2</sub> H <sub>4</sub> N <sub>2</sub> O	N-Cyanoacetamide.....	25	0.04–0.0013	381	$1.5 \times 10^{-4}$	(26); cf. (237)
C <sub>2</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	Hydantoin.....	25	0.03–0.004	388	$6.3 \times 10^{-10}$	(557, 624)
C <sub>2</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	Dioximinopropionic acid (labile).....	25	0.03–0.002	384	$4.1 \times 10^{-3}$	(244)
C <sub>2</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	Dioximinopropionic acid (stable).....	25	0.03–0.001	384	$2.80 \times 10^{-3}$	(244)
C <sub>2</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	Oxaluric acid.....	25	0.03–0.001	387	$\Lambda_{0.016} = 303$	(436)
					$\Lambda_{0.016} = 105$	(557)
C <sub>2</sub> H <sub>4</sub> N <sub>4</sub> O <sub>2</sub>	N-Methyltetrazolecarboxylic acid.....	20	0.016	(?)	$\Lambda_{0.016} = 208.7$	(429)
		0–40	0.016			(429)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Acrylic acid.....	18	0.03–0.001	350	$5.6 \times 10^{-5}$	(407)
		25	0.12–0.001	387	$5.5 \times 10^{-5}$	(436)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Pyroracemic acid (pyruvic acid).....	25	0.14–0.001	386	$3.2 \times 10^{-3}$	(76, 287); cf. (436)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Lambda_0$	<i>k</i> (or $\Lambda_0$ )	Lit.
Formula	Name					
C <sub>3</sub> H <sub>4</sub> O <sub>4</sub>	Malonic acid.....	0	0.1–0.02	247	$1.44 \times 10^{-3}$	(591)
		25	0.06–0.001	384	$1.60 \times 10^{-3}$	(49, 436, 577)
		0–35	0.5–0.0005			(45, 328, 609)
C <sub>3</sub> H <sub>4</sub> O <sub>4</sub>	Tartronic acid.....	25	0.09–0.002	383	$1.05 \times 10^{-1}$	(436)
					$4.9 \times 10^{-3}$	(519)
C <sub>3</sub> H <sub>5</sub> BrO <sub>2</sub>	$\alpha$ -Bromopropionic acid.....	25	0.008–0.001	382	$1.06 \times 10^{-3}$	(579)
		0–35	0.03–0.0005			(610)
C <sub>3</sub> H <sub>5</sub> BrO <sub>2</sub>	$\beta$ -Bromopropionic acid.....	25	0.03–0.001	382	$9.5 \times 10^{-3}$	(579)
C <sub>3</sub> H <sub>5</sub> ClO <sub>2</sub>	$\alpha$ -Chloropropionic acid.....	25	0.06–0.001	385	$1.6 \times 10^{-3}$	(344)
C <sub>3</sub> H <sub>5</sub> ClO <sub>2</sub>	$\beta$ -Chloropropionic acid.....	25	0.06–0.001	385	$8.4 \times 10^{-3}$	(344)
C <sub>3</sub> H <sub>5</sub> ClO <sub>2</sub>	$\alpha$ -Hydroxy- $\beta$ -chloropropionic acid.....	25	0.06–0.001	385	$7.5 \times 10^{-4}$	(523)
C <sub>3</sub> H <sub>5</sub> IQ <sub>2</sub>	$\beta$ -Iodopropionic acid.....	25	0.06–0.001	385	$8.8 \times 10^{-3}$	(436)
		0–35	0.12–0.0005			(610)
C <sub>3</sub> H <sub>5</sub> NO <sub>2</sub>	Isonitrosoacetone.....	25	0.05–0.02	386	$3 \times 10^{-3}$	(362); cf. (180, 342)
C <sub>3</sub> H <sub>5</sub> NO <sub>2</sub> S <sub>2</sub>	Dithiocarbamineglycolic acid.....	25	0.06–0.001	385	$5 \times 10^{-4}$	(286)
C <sub>3</sub> H <sub>5</sub> NO <sub>2</sub>	Nitroacetone.....	25	0.03–0.004	385	$1.0 \times 10^{-5}$	(360); cf. (256)
C <sub>3</sub> H <sub>5</sub> NO <sub>2</sub>	$\alpha$ -Oximinopropionic acid.....	25	0.06–0.001	385	$4.8 \times 10^{-4}$	(244, 291)
C <sub>3</sub> H <sub>5</sub> NO <sub>2</sub>	$\beta$ -Oximinopropionic acid.....	25	0.016–0.001	385	$9.8 \times 10^{-5}$	(244)
C <sub>3</sub> H <sub>5</sub> NO <sub>2</sub> S	Carbaminethioglycolic acid.....	25	0.12–0.001	386	$2.5 \times 10^{-4}$	(286, 436)
C <sub>3</sub> H <sub>5</sub> NO <sub>2</sub> S	Thiocarbamineglycolic acid.....	25	0.06–0.001	386	$1.12 \times 10^{-3}$	(286)
C <sub>3</sub> H <sub>5</sub> NO <sub>2</sub>	Aminomalonic acid.....	25	0.06–0.002	384	$7.60 \times 10^{-4}$	(370)
C <sub>3</sub> H <sub>5</sub> NO <sub>2</sub>	$\beta$ -Nitropropionic acid.....	25	0.03–0.002	382	$1.55 \times 10^{-4}$	(579)
C <sub>3</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	$\alpha$ -Triazopropionic acid.....	25	0.06–0.003	386	$8.7 \times 10^{-4}$	(453)
C <sub>3</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	Nitromalonamide.....	25	0.008–0.002	382	$5.8 \times 10^{-4}$	(232)
C <sub>3</sub> H <sub>5</sub> N <sub>3</sub> O	Ethyleneurea.....	25	0.03–0.004	(?)	$\Lambda_{0.02} = 0.35$	(557)
C <sub>3</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub> S	Ethylsulfonocyanamide.....	25	0.01–0.001	373	$[7 \times 10^{-7}]$	(26)
C <sub>3</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	<i>anti</i> -Diazourethane.....	0	0.016–0.002	246	$1.4 \times 10^{-6}$	(250)
C <sub>3</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	Malondihydroxyamic acid.....	25	0.03–0.008	385	$6 \times 10^{-8}$	(426)
C <sub>3</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	Ethyl nitrocarbamate.....	0	0.06–0.004	246	$3.0 \times 10^{-4}$	(43)
		10	0.06–0.004	299	$3.5 \times 10^{-4}$	(43)
		20	0.06–0.004	355	$4.4 \times 10^{-4}$	(43, 237)
		25	0.06–0.004	384	$5.0 \times 10^{-4}$	(43, 237)
		30	0.06–0.004	412	$5.2 \times 10^{-4}$	(43)
		40	0.06–0.004	465	$5.8 \times 10^{-4}$	(43)
C <sub>3</sub> H <sub>6</sub> O	Acetone.....	25	0.5	(?)	$\Lambda_{0.5} = 0.017$	(581)
C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	Propionic acid.....	25	0.12–0.001	386	$1.32 \times 10^{-3}$	(163, 200, 436)
		–1 to 65	1.0–0.0005			(11, 35, 37, 118, 293, 437, 558, 609, 611, 619); cf. (308)
C <sub>3</sub> H <sub>4</sub> O <sub>3</sub>	Hydraacrylic acid.....	25	0.03–0.001	385	$2.95 \times 10^{-3}$	(378, 436)
C <sub>3</sub> H <sub>4</sub> O <sub>3</sub>	Lactic acid.....	25	0.20–0.0004	385	$1.36 \times 10^{-4}$	(76, 376, 436); cf. (142)
C <sub>3</sub> H <sub>4</sub> O <sub>3</sub>	Methoxyacetic acid.....	25	0.06–0.001	385	$3.29 \times 10^{-4}$	(436)
					$2.94 \times 10^{-4}$	(436)
C <sub>3</sub> H <sub>4</sub> O <sub>4</sub>	$\alpha, \beta$ -Glyceric acid.....	25	1.0–0.001	384	$2.23 \times 10^{-4}$	(376, 436)
					$2.75 \times 10^{-4}$	(88)
C <sub>3</sub> H <sub>7</sub> ClO <sub>2</sub>	$\alpha$ -Monochlorohydrin.....	25	1.0–0.5	(?)	$\Lambda_{0.5} = 0.017$	(65, 77)
C <sub>3</sub> H <sub>7</sub> N	Allylamine.....	25	0.12–0.004	241	$4.9 \times 10^{-5}$	(104)
		0–46	0.06			(251)
C <sub>3</sub> H <sub>7</sub> NO	Acetoxime.....	25	0.03–0.004	383	$\Lambda_{0.02} = 0.07$	(557)
C <sub>3</sub> H <sub>7</sub> NO <sub>2</sub>	$\alpha$ -Aminopropionic acid.....	25	0.016–0.001	378	$\Lambda_{0.016} = 0.36$	(200); cf. (44, 197, 517)
C <sub>3</sub> H <sub>7</sub> NO <sub>2</sub>	Methylaminoacetic acid.....	25	0.0011	(?)	$\Lambda_{0.0011} = 244$	(200)
C <sub>3</sub> H <sub>7</sub> NO <sub>2</sub>	Propionohydroxyamic acid.....	25	0.06–0.03	385	$2.7 \times 10^{-3}$	(426)
C <sub>3</sub> H <sub>7</sub> N <sub>3</sub> O	Ethylisourea.....	25	0.12–0.004	235	$1.05 \times 10^{-4}$	(107)
C <sub>3</sub> H <sub>8</sub> O <sub>2</sub>	Propane-1, 2-diol.....	25	0.5	(?)	$\Lambda_{0.5} = 0.009$	(77)
C <sub>3</sub> H <sub>8</sub> O <sub>2</sub>	Propane-1, 3-diol.....	25	1.0–0.03	(?)	$\Lambda_{0.5} = 0.009$	(85, 77)
C <sub>3</sub> H <sub>8</sub> O <sub>3</sub>	Glycerol.....	25	8–0.03	(?)	$\Lambda_{0.5} = 0.007$	(77, 82)
C <sub>3</sub> H <sub>8</sub> O <sub>3</sub> S	Monopropyl sulfate.....	25	0.03–0.001	(?)	$\Lambda_{0.03} = 356$	(424)
C <sub>3</sub> H <sub>9</sub> N	<i>n</i> -Propylamine.....	25	0.25–0.001	239	$3.9 \times 10^{-4}$	(104, 433)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>3</sub> H <sub>9</sub> N	Isopropylamine.....	25	0.12-0.004	239	4.3 × 10 <sup>-4</sup>	(104)
C <sub>3</sub> H <sub>9</sub> N	Trimethylamine.....	25	0.06-0.001	244.5	6.5 × 10 <sup>-5</sup>	(110); cf. (104)
		0-35	0.03			(251)
C <sub>3</sub> H <sub>7</sub> O <sub>4</sub> P	Monoglyceryl phosphate.....	25	0.125-0.002	383	Λ <sub>0.125</sub> = 190	(120)
C <sub>3</sub> H <sub>10</sub> N <sub>2</sub>	Trimethylenediamine.....	25	0.06-0.004	234	2.8 × 10 <sup>-4</sup>	(104, 420)
C <sub>2</sub> H <sub>10</sub> OS	Trimethylsulfonium hydroxide....	25	0.5-0.004	245	Λ <sub>0.05</sub> = 222	(495)
C <sub>2</sub> H <sub>10</sub> OSn	Tin trimethyl hydroxide.....	25	0.06-0.004	231	1.5 × 10 <sup>-7</sup>	(104)
C <sub>2</sub> H <sub>10</sub> OTe	Tellurium trimethyl hydroxide....	25	0.06-0.004	236	Λ <sub>0.05</sub> = 210	(104)
C <sub>2</sub> HN <sub>3</sub>	Cyanoform.....	0	0.03-0.001	(?)	Λ <sub>0.03</sub> = 230	(245)
		25	0.03-0.001	393	Λ <sub>0.03</sub> = 362	(245)
C <sub>4</sub> H <sub>2</sub> Br <sub>2</sub> N <sub>2</sub> O <sub>2</sub>	Dibromobarbituric acid.....	25	0.016-0.001	384	8.4 × 10 <sup>-6</sup>	(557)
C <sub>4</sub> H <sub>2</sub> Cl <sub>2</sub> N <sub>2</sub> O <sub>2</sub>	Dichlorobarbituric acid.....	25	0.016-0.001	384	1.7 × 10 <sup>-6</sup>	(557)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Alloxan.....	25	0.03-0.008	384	2.3 × 10 <sup>-7</sup>	(624); cf. (116, 557)
					5 × 10 <sup>-9</sup>	(85); cf. (116, 557)
C <sub>4</sub> H <sub>2</sub> NiO <sub>4</sub> S <sub>4</sub>	Nickelodithiooxalic acid.....	25	0.0014-0.0007	(?)	Λ <sub>0.0014</sub> = 735	(477)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> Pt	Platinocyanic acid.....	25	0.03-0.001	(?)	Λ <sub>0.03</sub> = 752	(575)
C <sub>4</sub> H <sub>2</sub> O <sub>4</sub>	Acetylenedicarboxylic acid.....	25	0.016-0.0005	(?)	Λ <sub>0.016</sub> = 497	(436)
C <sub>4</sub> H <sub>2</sub> BrO <sub>4</sub>	Bromomaleic acid.....	25	0.06-0.0002	381	Λ <sub>0.06</sub> = 254	(436)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Nitrouacil.....	25	0.008-0.001	383	3.19 × 10 <sup>-6</sup>	(557)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Violuric acid.....	0	0.03	244	1.4 × 10 <sup>-6</sup>	(216)
		25	0.03-0.002	382	2.67 × 10 <sup>-5</sup>	(216, 380)
		35.5	0.03	443	3.26 × 10 <sup>-5</sup>	(216)
		14.5-54.1	0.03			(216)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Nitrobarbituric acid.....	25	0.03-0.001	382	Λ <sub>0.016</sub> = 347	(276, 557)
C <sub>4</sub> H <sub>2</sub> Br <sub>2</sub> O <sub>4</sub>	Isodibromosuccinic acid.....	25	0.015-0.0002	381	Λ <sub>0.015</sub> = 302	(524)
C <sub>4</sub> H <sub>2</sub> Br <sub>2</sub> O <sub>4</sub>	sym.-Dibromosuccinic acid.....	25	0.03-0.0009	381	Λ <sub>0.03</sub> = 262	(524, 577)
		0-65	0.03-0.0005			(526)
C <sub>4</sub> H <sub>2</sub> Cl <sub>2</sub> O <sub>4</sub>	fum.-2, 3-Dichlorosuccinic acid....	25	0.03-0.001	377	Λ <sub>0.03</sub> = 253	(400)
C <sub>4</sub> H <sub>2</sub> Cl <sub>2</sub> O <sub>4</sub>	mal.-2, 3-Dichlorosuccinic acid....	25	0.06-0.001	377	Λ <sub>0.03</sub> = 269	(400)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Barbituric acid.....	25	0.03-0.001	384	9.6 × 10 <sup>-6</sup>	(557)
					10.5 × 10 <sup>-5</sup>	(624)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Methyl cyanonitrosoacetate.....	0	0.06-0.016	249	1.4 × 10 <sup>-5</sup>	(411)
		18	0.06-0.016	352	2.3 × 10 <sup>-5</sup>	(411)
		25	0.06-0.001	390	2.8 × 10 <sup>-5</sup>	(410, 411)
		35	0.03-0.016	448	3.1 × 10 <sup>-5</sup>	(411)
		40	0.016	477	3.3 × 10 <sup>-5</sup>	(411)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Methyloximino-syn-oxazolone.....	0	0.03-0.012	245	8 × 10 <sup>-6</sup>	(216, 217)
		25	0.03-0.012	384	3.4 × 10 <sup>-6</sup>	(216, 217)
		35.5	0.03-0.012	445	5.7 × 10 <sup>-5</sup>	(216, 217)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Methylparabanic acid.....	25	0.03-0.001	(?)	[Λ <sub>0.03</sub> = 2.72]	(557)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Dialuric acid.....	25	0.008-0.001	381	6 × 10 <sup>-6</sup>	(85); cf. (557)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	α, α-Dioximinosuccinic acid.....	25	0.06-0.004	381	1.0 × 10 <sup>-2</sup>	(244)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	β, β-Dioximinosuccinic acid.....	25	0.06-0.001	381	Λ <sub>0.06</sub> = 238	(244)
C <sub>4</sub> H <sub>2</sub> N <sub>4</sub>	C-Methyl cyanoosotriazole.....	25	0.008	(?)	Λ <sub>0.008</sub> = 4.00	(429)
		0-40	0.008			(429)
C <sub>4</sub> H <sub>2</sub> O <sub>2</sub>	Tetrolic acid.....	25	0.03-0.0005	388	2.41 × 10 <sup>-3</sup>	(436)
C <sub>4</sub> H <sub>2</sub> O <sub>2</sub> S	α, β-Thiocrotonic acid.....	24	0.016-0.001	380	2.2 × 10 <sup>-4</sup>	(468)
C <sub>4</sub> H <sub>2</sub> O <sub>4</sub>	Fumaric acid.....	25	0.04-0.002	383	9.1 × 10 <sup>-4</sup>	(86, 436)
		0-65	0.03-0.0005			(45, 328, 525, 609)
C <sub>4</sub> H <sub>2</sub> O <sub>4</sub>	Maleic acid.....	18	0.12-0.0005	343	1.37 × 10 <sup>-2</sup>	(162)
		25	0.06-0.001	383	1.15 × 10 <sup>-2</sup>	(436, 476)
		0-65	0.12-0.0005			(45, 84, 86, 328, 525, 609)
C <sub>4</sub> H <sub>2</sub> O <sub>4</sub>	Hydroxyfumaric acid.....	17	0.10-0.0016	340	2.72 × 10 <sup>-3</sup>	(623)
C <sub>4</sub> H <sub>2</sub> O <sub>4</sub>	Hydroxymaleic acid.....	17	0.10-0.0016	340	2.46 × 10 <sup>-3</sup>	(623)
C <sub>4</sub> H <sub>2</sub> O <sub>4</sub>	Dihydroxyfumaric acid.....	25	0.016-0.002	383	[7.7 × 10 <sup>-2</sup> ]	(519); cf. (87)
C <sub>4</sub> H <sub>2</sub> O <sub>4</sub>	Dihydroxymaleic acid.....	25	0.016-0.008	383	[6.7 × 10 <sup>-2</sup> ]	(519); cf. (87, 350)
C <sub>4</sub> H <sub>2</sub> BrO <sub>4</sub>	dl-Bromosuccinic acid.....	25	0.03-0.002	382	2.70 × 10 <sup>-3</sup>	(577)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	$\alpha$ -Range	$\Lambda_0$	<i>k</i> (or $\Lambda_c$ )	Lit.
Formula	Name					
C <sub>4</sub> H <sub>5</sub> BrO <sub>4</sub>	<i>dl</i> -Bromosuccinic acid.—(Cont'd)	0–25	0.008–0.0005			(525)
C <sub>4</sub> H <sub>5</sub> BrO <sub>4</sub>	<i>l</i> -Bromosuccinic acid.....	25	(?)	382	$2.70 \times 10^{-3}$	(570)
C <sub>4</sub> H <sub>5</sub> ClN <sub>2</sub>	<i>N</i> -Methylchloroglyoxaline.....	25	0.06–0.008	238	$1.8 \times 10^{-8}$	(148)
C <sub>4</sub> H <sub>5</sub> ClO <sub>2</sub>	$\alpha$ -Chlorocrotonic acid.....	25	0.06–0.001	384	$7.0 \times 10^{-4}$	(436)
C <sub>4</sub> H <sub>5</sub> ClO <sub>2</sub>	$\beta$ -Chlorocrotonic acid.....	25	0.06–0.001	384	$1.42 \times 10^{-4}$	(436)
C <sub>4</sub> H <sub>5</sub> ClO <sub>2</sub>	$\alpha$ -Chloroisocrotonic acid.....	25	0.06–0.001	384	$1.55 \times 10^{-3}$	(436)
C <sub>4</sub> H <sub>5</sub> ClO <sub>2</sub>	$\beta$ -Chloroisocrotonic acid.....	25	0.06–0.001	384	$9.3 \times 10^{-5}$	(436)
C <sub>4</sub> H <sub>5</sub> ClO <sub>2</sub>	1-Chlorocyclopropanecarboxylic acid.....	[25]	(?)	(?)	$5.5 \times 10^{-4}$	(111)
C <sub>4</sub> H <sub>5</sub> ClO <sub>4</sub>	<i>dl</i> -Chlorosuccinic acid.....	25	0.03–0.002	382	$2.85 \times 10^{-3}$	(577)
C <sub>4</sub> H <sub>5</sub> ClO <sub>4</sub>	<i>d</i> -Chlorosuccinic acid.....	25	(?)	382	$2.85 \times 10^{-3}$	(570)
C <sub>4</sub> H <sub>5</sub> ClO <sub>4</sub>	<i>l</i> -Chlorosuccinic acid.....	25	(?)	382	$2.85 \times 10^{-3}$	(570)
C <sub>4</sub> H <sub>5</sub> ClO <sub>6</sub>	Chloromalic acid.....	25	0.06–0.001	382	$4.7 \times 10^{-3}$	(523)
C <sub>4</sub> H <sub>5</sub> Cl <sub>3</sub> O <sub>2</sub>	$\alpha$ , $\alpha$ , $\beta$ -Trichlorobutyric acid.....	25	0.37–0.0016	379	$\Lambda_{0.02} = 333$	(145, 312, 313, 436, 466)
		18	0.11–0.0017			(162, 419)
C <sub>4</sub> H <sub>5</sub> NO <sub>2</sub>	Methyl cyanoacetate.....	25	0.03–0.016	(?)	$\Lambda_{0.03} = 0.33$	(213)
C <sub>4</sub> H <sub>5</sub> NO <sub>2</sub>	$\gamma$ -Methylisoxazolone.....	20	0.004	(?)	$\Lambda_{0.004} = 112.3$	(429)
		0–40				(429)
C <sub>4</sub> H <sub>5</sub> NO <sub>2</sub>	Succinimide.....	25	0.06–0.016	385	$\Lambda_{0.03} = 0.5$	(343, 577)
C <sub>4</sub> H <sub>5</sub> NO <sub>2</sub>	$\alpha$ -Oximosuccinic acid.....	25	0.03–0.004	383	$1.1 \times 10^{-3}$	(244)
C <sub>4</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	<i>N</i> -Methylsotriazolecarboxylic acid.....	25	0.008	(?)	$\Lambda_{0.008} = 88.5$	(429)
		0–40				(429)
C <sub>4</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	3-Methyl-4-isonitrosopyrazolone..	15	0.005–0.003	325	$8.8 \times 10^{-7}$	(362)
		25	0.008–0.001	381	$1.18 \times 10^{-8}$	(362); cf. (235)
		40	0.005–0.003	462	$1.70 \times 10^{-8}$	(362)
C <sub>4</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub>	4-Methyl-1-hydroxy-1, 2, 5-triazole-3-carboxylic acid.....	21.5	0.04–0.003	355	$6.0 \times 10^{-3}$	(175)
C <sub>4</sub> H <sub>5</sub> Br <sub>2</sub> O <sub>4</sub> S	$\beta$ -Dibromomethylsulfonepropionic acid.....	25	0.06–0.004	377	$1.97 \times 10^{-4}$	(358)
C <sub>4</sub> H <sub>5</sub> Cl <sub>2</sub> O <sub>2</sub>	<i>fum.</i> - $\alpha$ , $\beta$ -Dichlorobutyric acid....	25	0.03–0.001	383	$5.9 \times 10^{-3}$	(400)
C <sub>4</sub> H <sub>5</sub> Cl <sub>2</sub> O <sub>2</sub>	<i>mal.</i> - $\alpha$ , $\beta$ -Dichlorobutyric acid....	25	0.06–0.004	383	$7.9 \times 10^{-3}$	(400)
C <sub>4</sub> H <sub>5</sub> Cl <sub>2</sub> O <sub>4</sub> S	$\beta$ -Dichloromethylsulfonepropionic acid.....	25	0.06–0.004	378	$1.95 \times 10^{-4}$	(358)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	<i>N</i> -Methylglyoxaline.....	25	0.06–0.002	245	$2.2 \times 10^{-7}$	(148)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	$\alpha$ -Methylglyoxaline.....	25	0.06–0.001	245	$4.2 \times 10^{-7}$	(148)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	$\mu$ -Methylglyoxaline.....	25	0.06–0.001	239	$1.3 \times 10^{-6}$	(148)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub>	Ethyl cyanocarbamate.....	25	0.02–0.0013	381	$4.7 \times 10^{-4}$	(26)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub>	Lactocyanamide.....	25	0.03–0.004	381	$[3 \times 10^{-7}]$	(26)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>4</sub>	<i>amphi</i> -Dioximinobutyric acid.....	25	0.008	384	$2 \times 10^{-5}$	(244)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>4</sub>	<i>syn</i> -Dioximinobutyric acid.....	25	0.03–0.004	384	$1.3 \times 10^{-3}$	(244)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>4</sub>	Ethyl tetrazolecarboxylate.....	20	0.03–0.004	385	$4.0 \times 10^{-6}$	(428)
		0–30				(428)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	$\alpha$ -Crotonic acid.....	25	0.12–0.001	384	$2.00 \times 10^{-5}$	(376, 436)
		0–65	0.12–0.0005			(525, 609)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	$\beta$ -Crotonic acid.....	25	0.12–0.001	384	$3.5 \times 10^{-5}$	(436)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Diacetyl.....	25	1–0.002	385	$4 \times 10^{-7}$	(78)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Trimethylenecarboxylic acid.....	25	0.07–0.0015	384	$1.68 \times 10^{-3}$	(99); cf. (93)
					$1.40 \times 10^{-5}$	(141, 487, 635)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Vinylacetic acid.....	25	0.06–0.001	387	$3.75 \times 10^{-5}$	(109); cf. (193)
					$4.6 \times 10^{-4}$	(635)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Vinylglycolic acid.....	25	0.06–0.001	384	$4.8 \times 10^{-4}$	(520)
C <sub>4</sub> H <sub>5</sub> O <sub>4</sub>	Succinic acid.....	25	0.12–0.0005	382	$6.7 \times 10^{-5}$	(54, 138)
					$6.5 \times 10^{-5}$	(86, 376, 436, 476, 565)
					$6.3 \times 10^{-5}$	(612)
		0–65	0.98–0.0005			(11, 45, 84, 126, 149, 328, 329, 450, 476, 507, 609)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>4</sub> H <sub>6</sub> O <sub>4</sub>	Isosuccinic acid.....	25	0.06-0.001	383	8.4 × 10 <sup>-4</sup>	(436, 577)
C <sub>4</sub> H <sub>6</sub> O <sub>4</sub> S	Thiodiglycolic acid.....	25	0.06-0.001	384	4.8 × 10 <sup>-4</sup>	(357, 436)
		0-65	0.12-0.0005			(610, 611)
C <sub>4</sub> H <sub>6</sub> O <sub>4</sub> S	Thiomalic acid.....	25	0.03-0.001	384	5.2 × 10 <sup>-4</sup>	(482)
C <sub>4</sub> H <sub>6</sub> O <sub>4</sub> S <sub>2</sub>	Dithiodiglycolic acid.....	25	0.03-0.016	385	6.7 × 10 <sup>-4</sup>	(436)
C <sub>4</sub> H <sub>6</sub> O <sub>4</sub> S <sub>3</sub>	Trithiodiacetic acid.....	25	0.08-0.0013	381	1.03 × 10 <sup>-3</sup>	(282)
C <sub>4</sub> H <sub>6</sub> O <sub>4</sub> Se	Selenodiglycolic acid.....	25	0.12-0.001	384	4.17 × 10 <sup>-4</sup>	(358)
C <sub>4</sub> H <sub>6</sub> O <sub>5</sub>	Diglycolic acid.....	25	0.016-0.001	383	1.08 × 10 <sup>-3</sup>	(79, 436)
C <sub>4</sub> H <sub>6</sub> O <sub>5</sub>	dl-Malic acid.....	25	0.016-0.001	382	3.9 × 10 <sup>-4</sup>	(436, 570)
C <sub>4</sub> H <sub>6</sub> O <sub>5</sub>	l-Malic acid.....	25	0.03-0.001	382	3.88 × 10 <sup>-4</sup>	(378, 436, 570)
		0-35	0.03-0.0005			(45, 525)
C <sub>4</sub> H <sub>6</sub> O <sub>6</sub>	dl-Tartaric acid.....	25	0.06-0.001	382	5.9 × 10 <sup>-4</sup>	(133, 577)
		17-37				(45, 112)
C <sub>4</sub> H <sub>6</sub> O <sub>6</sub>	d-Tartaric acid.....	18	0.1-0.0004	346	9.7 × 10 <sup>-4</sup>	(440)
		25	1.0-0.004	382	9.6 × 10 <sup>-4</sup>	(73, 211, 375, 436, 577)
		76	0.1-0.008	619	1.03 × 10 <sup>-3</sup>	(440)
		0-42	1.0-0.05			(45, 50, 113, 121, 123, 298, 326, 351, 463, 472, 496, 527, 555)
C <sub>4</sub> H <sub>6</sub> O <sub>6</sub>	l-Tartaric acid.....	25	0.06-0.004	382	9.6 × 10 <sup>-4</sup>	(133, 436, 577)
		0-65	0.12-0.0005			(112, 610, 611)
C <sub>4</sub> H <sub>6</sub> O <sub>6</sub>	para-Tartaric acid.....	25	0.12-0.004	382	9.6 × 10 <sup>-4</sup>	(73, 211, 436, 577)
		0-65	0.12-0.0005			(45, 50, 112, 299, 525, 609)
C <sub>4</sub> H <sub>6</sub> O <sub>6</sub> S	Sulfonediacetic acid.....	25	0.06-0.001	384	1.26 × 10 <sup>-3</sup>	(357)
C <sub>4</sub> H <sub>6</sub> O <sub>8</sub>	Dihydroxytartaric acid.....	25	0.06-0.001	381	[1.2 × 10 <sup>-3</sup> ]	(519)
C <sub>4</sub> H <sub>7</sub> BrO <sub>2</sub>	α-Bromobutyric acid.....	25	0.008-0.001	381	1.03 × 10 <sup>-3</sup>	(579)
		0-35	0.03-0.0005			(610)
C <sub>4</sub> H <sub>7</sub> BrO <sub>2</sub>	γ-Bromobutyric acid.....	25	0.03-0.015	383	2.6 × 10 <sup>-5</sup>	(344)
C <sub>4</sub> H <sub>7</sub> ClO <sub>2</sub>	α-Chlorobutyric acid.....	25	0.06-0.001	383	1.45 × 10 <sup>-3</sup>	(344)
C <sub>4</sub> H <sub>7</sub> ClO <sub>2</sub>	β-Chlorobutyric acid.....	25	0.06-0.001	383	8.8 × 10 <sup>-5</sup>	(344)
C <sub>4</sub> H <sub>7</sub> ClO <sub>2</sub>	γ-Chlorobutyric acid.....	25	0.03-0.015	383	[Λ <sub>0.03</sub> = 12.2]	(344)
C <sub>4</sub> H <sub>7</sub> ClO <sub>3</sub>	α-Chloro-β-hydroxybutyric acid...	25	0.025-0.0008	383	2.5 × 10 <sup>-3</sup>	(523)
C <sub>4</sub> H <sub>7</sub> ClO <sub>3</sub>	α-Hydroxy-β-chlorobutyric acid...	25	0.06-0.0005	383	8.1 × 10 <sup>-4</sup>	(523)
C <sub>4</sub> H <sub>7</sub> ClO <sub>3</sub>	α-Hydroxy-β-chloroisobutyric acid.	25	0.06-0.0005	383	6.2 × 10 <sup>-4</sup>	(523)
C <sub>4</sub> H <sub>7</sub> F <sub>4</sub> N	Tetrafluorodiethylamine.....	25	0.06	(?)	Λ <sub>0.06</sub> = 0.12	(545)
C <sub>4</sub> H <sub>7</sub> F <sub>4</sub> O <sub>4</sub> P	Tetrafluorodiethyl phosphate.....	25	0.03-0.001	383	Λ <sub>0.03</sub> = 347	(288)
C <sub>4</sub> H <sub>7</sub> IO <sub>2</sub>	γ-Iodobutyric acid.....	25	0.03-0.015	383	2.3 × 10 <sup>-5</sup>	(344)
C <sub>4</sub> H <sub>7</sub> NO <sub>2</sub>	Acetylaminocetic acid.....	25	0.06-0.001	381	2.25 × 10 <sup>-4</sup>	(436)
C <sub>4</sub> H <sub>7</sub> NO <sub>2</sub>	α-Oximino-butyric acid.....	25	0.06-0.001	384	7.0 × 10 <sup>-4</sup>	(291); cf. (244)
C <sub>4</sub> H <sub>7</sub> NO <sub>4</sub>	Aminosuccinic acid.....	25	0.03-0.001	381	Λ <sub>0.03</sub> = 17.2	(537, 577, 622); cf. (45)
C <sub>4</sub> H <sub>7</sub> NO <sub>4</sub>	Diglycolamic acid.....	25	0.03-0.001	380	Λ <sub>0.03</sub> = 63.4	(537)
C <sub>4</sub> H <sub>7</sub> NO <sub>4</sub>	l-Malamic acid.....	25	0.03-0.001	383	2.76 × 10 <sup>-4</sup>	(369)
C <sub>4</sub> H <sub>7</sub> NO <sub>4</sub>	Ethyl nitroacetate.....	25	0.04-0.002	384	1.4 × 10 <sup>-5</sup>	(342, 498)
C <sub>4</sub> H <sub>8</sub> N <sub>2</sub> O <sub>2</sub>	Aminosuccinamic acid.....	25	0.06-0.004	380	Λ <sub>0.06</sub> = 0.096	(588); cf. (577, 622)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	n-Butyric acid.....	25	0.12-0.001	383	1.50 × 10 <sup>-5</sup>	(53, 163, 200, 376, 436, 619)
		0-65	0.5-0.0001			(11, 35, 37, 273, 328, 437, 525, 558, 609)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Isobutyric acid.....	25	0.06-0.001	383	1.41 × 10 <sup>-5</sup>	(141, 200, 436)
		0-65	1.0-0.0005		1.55 × 10 <sup>-5</sup>	(53, 163)
						(293, 525, 558, 609)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub> S	Ethylthioglycolic acid.....	25	0.07-0.002	383	1.80 × 10 <sup>-4</sup>	(465)
C <sub>4</sub> H <sub>8</sub> O <sub>3</sub>	Ethoxyacetic acid.....	25	0.06-0.001	383	2.30 × 10 <sup>-4</sup>	(436)
C <sub>4</sub> H <sub>8</sub> O <sub>3</sub>	α-Hydroxybutyric acid.....	25	1.0-0.0005	385	6 × 10 <sup>-5</sup>	(10, 432)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	$\Delta_0$	k(or $\Delta_c$ )	Lit.
Formula	Name					
C <sub>4</sub> H <sub>8</sub> O <sub>3</sub>	$\alpha$ -Hydroxybutyric acid.—(Cont'd)					
C <sub>4</sub> H <sub>8</sub> O <sub>3</sub>	$\beta$ -Hydroxybutyric acid.....	25	0.48-0.0005	385	$1.05 \times 10^{-4}$ $3.03 \times 10^{-5}$	(67) (525.1); cf. (10)
C <sub>4</sub> H <sub>8</sub> O <sub>3</sub>	$\gamma$ -Hydroxybutyric acid.....	25	0.013-0.003	385	$3.3 \times 10^{-5}$ $1.90 \times 10^{-5}$	(67) (262)
C <sub>4</sub> H <sub>8</sub> O <sub>3</sub>	Hydroxyisobutyric acid.....	25	0.06-0.001	382	$1.03 \times 10^{-4}$	(378, 436)
		0-65	0.12-0.0005			(610, 611)
C <sub>4</sub> H <sub>8</sub> O <sub>3</sub>	$\alpha$ -Methoxypropionic acid.....	25	(?)	(?)	$3.04 \times 10^{-4}$	(438)
C <sub>4</sub> H <sub>8</sub> O <sub>3</sub>	$\beta$ -Methoxypropionic acid.....	25	(?)	(?)	$3.46 \times 10^{-5}$	(438)
C <sub>4</sub> H <sub>8</sub> N	Methylene cyclopropaneamine.....	25	0.07-0.002	235	$3.5 \times 10^{-4}$	(141)
C <sub>4</sub> H <sub>9</sub> NO <sub>2</sub>	$\gamma$ -Aminobutyric acid.....	25	0.03	(?)	$\Delta_{0.03} = 0.2$	(340)
C <sub>4</sub> H <sub>9</sub> NO <sub>2</sub>	Butyrylhydroxamic acid.....	25	0.06-0.03	383	$2.3 \times 10^{-5}$	(426)
C <sub>4</sub> H <sub>9</sub> NO <sub>2</sub>	Dimethylaminoacetic acid.....	25	(?)	(?)	$[2 \times 10^{-7}]$	(297)
C <sub>4</sub> H <sub>9</sub> NO <sub>4</sub>	2, 2-Nitromethylpropane-1, 3-diol.	25	1-0.125	(?)	$\Delta_{1.0} = 0.017$	(68)
C <sub>4</sub> H <sub>9</sub> NO <sub>5</sub>	Nitrotricarbinolmethane.....	25	1.7-0.125	(?)	$\Delta_{0.5} = 0.026$	(65)
C <sub>4</sub> H <sub>9</sub> O <sub>5</sub> P	Erythritolphosphoric acid.....	25	0.125-0.002	383	$\Delta_{0.125} = 212$	(120)
C <sub>4</sub> H <sub>10</sub> N <sub>2</sub>	Diethylenediamine.....	25	0.03-0.004	233	$5.3 \times 10^{-5}$	(104)
C <sub>4</sub> H <sub>10</sub> N <sub>2</sub> O <sub>4</sub>	Glycoliminohydrin.....	25	0.016-0.001	(?)	$\Delta_{0.016} = 71.5$	(255)
C <sub>4</sub> H <sub>10</sub> N <sub>2</sub> O <sub>5</sub>	Dinitroethane alcoholate.....	25	0.008-0.001	383	$1.7 \times 10^{-4}$	(247)
C <sub>4</sub> H <sub>10</sub> O	Ethyl ether.....	25	0.5	(?)	$\Delta_{0.5} = 0.065$	(581)
C <sub>4</sub> H <sub>10</sub> O <sub>2</sub>	n-Butane-1, 4-diol.....	25	1.0-0.5	(?)	$\Delta_{1.0} = 0.022$	(65)
C <sub>4</sub> H <sub>10</sub> O <sub>2</sub> S	Dimethylthetin.....	25	0.06-0.004	(?)	$\Delta_{0.06} = 2.1$ $\Delta_{0.06} = 0.87$	(119) (415)
C <sub>4</sub> H <sub>10</sub> O <sub>4</sub> S	Monoisobutyl sulfate.....	25	0.03-0.001	(?)	$\Delta_{0.03} = 350$	(434)
C <sub>4</sub> H <sub>11</sub> N	Diethylamine.....	25	0.12-0.004	234	$1.01 \times 10^{-3}$	(104)
C <sub>4</sub> H <sub>11</sub> N	Isobutylamine.....	25	0.25-0.001	235	$2.6 \times 10^{-4}$	(104); cf. (141, 433)
C <sub>4</sub> H <sub>11</sub> N	sec.-Butylamine.....	25	0.12-0.004	235	$3.6 \times 10^{-4}$	(104)
C <sub>4</sub> H <sub>11</sub> N	tert.-Butylamine.....	25	0.12-0.004	235	$2.8 \times 10^{-4}$	(104)
C <sub>4</sub> H <sub>11</sub> O <sub>4</sub> P	Diethyl phosphate.....	25	0.125-0.001	383	$\Delta_{0.07} = 304$	(164, 288)
C <sub>4</sub> H <sub>11</sub> O <sub>4</sub> P	Monoisobutyl phosphate.....	25	0.125-0.002	383	$\Delta_{0.125} = 152$	(120)
C <sub>4</sub> H <sub>11</sub> OTl	Thallium diethyl hydroxide.....	25	0.10-0.003	(?)	$\Delta_{0.10} = 146$	(509)
C <sub>4</sub> H <sub>12</sub> INO	Trimethyliodomethylammonium hydroxide.....	25	0.06-0.004	235	$\Delta_{0.06} = 210$	(104)
C <sub>4</sub> H <sub>12</sub> N <sub>2</sub>	Tetramethylenediamine.....	25	0.03-0.004	231	$4.1 \times 10^{-4}$	(104, 430)
C <sub>4</sub> H <sub>12</sub> AsO	Tetramethylarsonium hydroxide...	25	0.06-0.004	236	$\Delta_{0.06} = 210$	(104)
C <sub>4</sub> H <sub>12</sub> NO	Tetramethylammonium hydroxide.	25	0.06-0.004	243	$\Delta_{0.06} = 219$	(104)
C <sub>4</sub> H <sub>12</sub> OP	Tetramethylphosphonium hydroxide.....	25	0.06-0.004	238	$\Delta_{0.06} = 214$	(104)
C <sub>4</sub> H <sub>12</sub> OSb	Tetramethylstibonium hydroxide..	25	0.06-0.004	230	$\Delta_{0.06} = 177$	(104)
C <sub>4</sub> HBr <sub>3</sub> O <sub>3</sub>	Tribromotriketopentamethylene...	[25]	0.03-0.001	(?)	$\Delta_{0.03} = 348$	(224)
C <sub>4</sub> HCl <sub>3</sub> O <sub>3</sub>	Trichlorotriketopentamethylene...	[25]	0.03-0.001	(?)	$\Delta_{0.03} = 346$	(224)
C <sub>4</sub> HCl <sub>3</sub> O <sub>3</sub>	1, 1, 3, 4, 4-Pentachloropentadiene-carboxylic acid.....	(?)	(?)	(?)	$6 \times 10^{-3}$	(636)
C <sub>4</sub> H <sub>2</sub> O <sub>3</sub>	Croconic acid.....	25	0.07-0.0003	(?)	$\Delta_{0.07} = 337$	(127)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>3</sub>	Nitrouacilcarboxylic acid.....	25	0.03-0.001	382	$\Delta_{0.03} = 339$	(557)
C <sub>4</sub> H <sub>2</sub> Br <sub>2</sub> O <sub>3</sub>	Acetyldibromoacrylic acid.....	25	0.01-0.0007	380	$6.0 \times 10^{-5}$	(7)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Methylalloxan.....	25	0.03-0.001	(?)	$\Delta_{0.03} = 9.9$	(557)
C <sub>4</sub> H <sub>2</sub> N <sub>2</sub> O <sub>5</sub>	Uric acid.....	18	0.00015	336	$2 \times 10^{-6}$	(267)
		37	0.0004	437	$3.2 \times 10^{-6}$	(212)
		0-35	0.0005			(610)
C <sub>4</sub> H <sub>4</sub> O <sub>2</sub>	Furfural.....	25	0.5	(?)	$\Delta_{0.5} = 0.15$	(581)
C <sub>4</sub> H <sub>4</sub> O <sub>2</sub> S	$\alpha$ -Thiophenecarboxylic acid.....	25	0.04-0.0008	385	$3.10 \times 10^{-5}$	(26, 436, 546)
C <sub>4</sub> H <sub>4</sub> O <sub>2</sub> S	$\beta$ -Thiophenecarboxylic acid.....	25	0.02-0.0006	385	$7.7 \times 10^{-5}$	(358, 566)
C <sub>4</sub> H <sub>4</sub> O <sub>3</sub>	Pyromeconic acid.....	25	0.03	(?)	$\Delta_{0.03} = 0.57$	(436)
C <sub>4</sub> H <sub>4</sub> O <sub>3</sub>	Pyromucic acid.....	25	0.06-0.001	385	$7.01 \times 10^{-5}$	(378, 436)
		0-65	0.12-0.0005			(526, 609)
C <sub>4</sub> H <sub>4</sub> O <sub>3</sub>	Isopyromucic acid.....	25	0.04-0.014	385	$3 \times 10^{-5}$	(122)
C <sub>4</sub> H <sub>4</sub> BrN <sub>2</sub> O <sub>3</sub>	Methylbromouracil.....	25	0.002-0.001	382	$2.5 \times 10^{-5}$	(557)
C <sub>4</sub> H <sub>4</sub> BrO <sub>3</sub>	Bromotetric acid.....	25	0.0015-0.0008	383	$1 \times 10^{-5}$	(573)
C <sub>4</sub> H <sub>4</sub> BrO <sub>4</sub>	Bromocitraconic acid.....	25	0.01-0.0012	380	$1.4 \times 10^{-3}$	(7)
C <sub>4</sub> H <sub>4</sub> ClN <sub>2</sub> O <sub>3</sub>	Methylchlorouracil.....	25	0.002-0.001	382	$3.2 \times 10^{-5}$	(557)
C <sub>4</sub> H <sub>4</sub> N	Pyridine.....	0	All concns.	(?)	Extremely small	(257)
		25	All concns.	(?)	Extremely small	(257)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formulas	Name					
C <sub>4</sub> H <sub>5</sub> NO <sub>2</sub>	Pyrrole-2-carboxylic acid.....	25	0.03-0.0008	385	3.9 × 10 <sup>-5</sup>	(7); cf. (278)
C <sub>4</sub> H <sub>5</sub> NO <sub>2</sub> S	4-Methylthiazole-5-carboxylic acid.....	25	0.008-0.0005	382	3.6 × 10 <sup>-4</sup>	(49)
C <sub>4</sub> H <sub>5</sub> NO <sub>2</sub>	Methyl cyanoformylacetate.....	25	0.03-0.001	384	Λ <sub>0.02</sub> = 187	(99)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>4</sub>	Methylnitroureacil.....	25	0.002-0.001	381	4.2 × 10 <sup>-7</sup>	(557)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>4</sub>	Methyl violurate.....	25	0.004-0.001	381	1.85 × 10 <sup>-7</sup>	(240)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	α-Aminopyridine.....	25	0.06-0.03	237	1.4 × 10 <sup>-7</sup>	(556)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	β-Aminopyridine.....	25	0.12-0.06	237	3.8 × 10 <sup>-8</sup>	(556)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	γ-Aminopyridine.....	25	0.12-0.008	237	1.33 × 10 <sup>-8</sup>	(556)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> OS	Methylthiouracil.....	25	0.002-0.001	383	4.5 × 10 <sup>-8</sup>	(557)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub>	Methyluracil.....	25	0.016-0.001	383	4.6 × 10 <sup>-9</sup>	(557)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub>	Dimethylparabanic acid.....	25	0.03-0.008	(?)	Λ <sub>0.02</sub> = 0.35	(557)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub>	Ethyl cyanonitrosoacetate.....	25	0.03-0.001	382	2.25 × 10 <sup>-8</sup>	(410)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub>	Succinylcyanamic acid.....	25	0.016-0.001	379	3.0 × 10 <sup>-4</sup>	(26)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub>	Uric acid glycol.....	25	0.004	(?)	Λ <sub>0.004</sub> = 3.27	(85)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Tetric acid.....	25	0.03-0.004	382	8.05 × 10 <sup>-5</sup>	(569)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Citraconic acid.....	25	0.10-0.001	381	3.33 × 10 <sup>-3</sup>	(436, 476)
		0-65	0.03-0.0005			(45, 328, 525, 609)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Glutaconic acid.....	0	0.04-0.0006	246	1.60 × 10 <sup>-4</sup>	(562)
		25	0.03-0.0008	383	1.72 × 10 <sup>-4</sup>	(562, 577)
		45	0.03-0.004			(559)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Itaconic acid.....	25	0.06-0.0007	381	1.18 × 10 <sup>-4</sup>	(436, 476)
					1.46 × 10 <sup>-4</sup>	(524)
		0-65	0.03-0.0005			(45, 525, 609)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Mesaconic acid.....	25	0.02-0.001	381	7.75 × 10 <sup>-4</sup>	(436, 577)
		0-65	0.03-0.0005			(45, 328, 525, 609) *
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Trimethylene-1, 1-dicarboxylic acid.....	25	0.03-0.002	380	1.95 × 10 <sup>-2</sup>	(99, 524)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	<i>fum.</i> -Trimethylene-1, 2-dicarboxylic acid.....	25	0.01-0.003	380	2.05 × 10 <sup>-4</sup>	(99)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	<i>mal.</i> -Trimethylene-1, 2-dicarboxylic acid.....	25	0.02-0.005	380	4.0 × 10 <sup>-4</sup>	(99)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub> S <sub>2</sub>	Trithiocarbonyldiglycolic acid.....	25	0.012-0.0015	378	2.6 × 10 <sup>-3</sup>	(285)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Acetonedicarboxylic acid.....	25	0.05-0.0016	379	7.7 × 10 <sup>-4</sup>	(7)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub> S <sub>2</sub>	Dithiocarbonyldiglycolic acid.....	25	0.06-0.001	378	1.6 × 10 <sup>-3</sup>	(285)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Ethenyltricarboxylic acid.....	25	0.03-0.001	379	3.1 × 10 <sup>-3</sup>	(578)
C <sub>4</sub> H <sub>5</sub> BrO <sub>2</sub>	Bromopyrotartaric acid.....	25	0.016-0.004	382	4.65 × 10 <sup>-3</sup>	(577)
C <sub>4</sub> H <sub>5</sub> NO <sub>2</sub>	Ethyl cyanoacetate.....	25	0.004-0.002	(?)	Λ <sub>0.004</sub> = 0.48	(573)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	α, α'-Diaminopyridine.....	25	0.06	235	6.4 × 10 <sup>-8</sup>	(556)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	α, γ-Diaminopyridine.....	25	0.12-0.008	235	1.28 × 10 <sup>-8</sup>	(556)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	β, β'-Diaminopyridine.....	25	0.12-0.06	235	1.0 × 10 <sup>-7</sup>	(556)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O	Methyliminouracil.....	25	0.008-0.001	383	3.7 × 10 <sup>-8</sup>	(557)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub>	N-Dimethyl cyanurate.....	25	0.016	(?)	Λ <sub>0.016</sub> = 0.26	(456)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	N-Ethylglyoxaline.....	25	0.06-0.001	237	2.5 × 10 <sup>-7</sup>	(148)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub>	μ-Ethylglyoxaline.....	25	0.06-0.001	238	1.0 × 10 <sup>-6</sup>	(148)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O	Butyrylcyanamide.....	25	0.03-0.0009	379	1.10 × 10 <sup>-4</sup>	(26)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub> S	Thiosuccinuric acid.....	25	0.016-0.001	379	3.26 × 10 <sup>-5</sup>	(436)
C <sub>4</sub> H <sub>5</sub> N <sub>2</sub> O <sub>2</sub>	Succinuric acid.....	25	0.016-0.001	378	3.05 × 10 <sup>-5</sup>	(436)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Acetylacetone.....	25	0.06-0.001	382	4.7 × 10 <sup>-8</sup>	(508)
					1.4 × 10 <sup>-6</sup>	(213)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Allylacetic acid.....	25	0.06-0.001	382	2.12 × 10 <sup>-5</sup>	(190)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Angellic acid.....	25	0.03-0.0005	382	4.9 × 10 <sup>-5</sup>	(436)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	β-Dimethylacrylic acid.....	[25]	(?)	(?)	2 × 10 <sup>-4</sup>	(448)
					2.2 × 10 <sup>-4</sup>	(451)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Ethylidenepropionic acid.....	25	0.06-0.001	382	3.47 × 10 <sup>-6</sup>	(190)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Propylideneacetic acid.....	25	0.06-0.001	382	1.51 × 10 <sup>-5</sup>	(190)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Tetramethylenecarboxylic acid.....	25	0.07-0.001	380	1.81 × 10 <sup>-5</sup>	(487, 582, 635)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Tiglic acid.....	25	0.03-0.001	382	9.4 × 10 <sup>-6</sup>	(436)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub> S	Tetrahydro-α-thiophenecarboxylic acid.....	25	0.06-0.002	383	1.11 × 10 <sup>-4</sup>	(26)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub> S <sub>2</sub>	Ethyltrithiocarbonylglycolic acid.....	25	0.01-0.0014	378	8.2 × 10 <sup>-4</sup>	(285)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Methyl acetoacetate.....	25	0.016	(?)	Λ <sub>0.016</sub> = 0.28	(213)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Lambda_0$	<i>k</i> (or $\Delta_c$ )	Lit.
Formula	Name					
C <sub>5</sub> H <sub>8</sub> O <sub>3</sub>	Levulinic acid.....	0	0.03–0.002	254	$2.2 \times 10^{-3}$	(217)
		25	0.03–0.001	378	$2.25 \times 10^{-3}$	(217)
					$2.50 \times 10^{-3}$	(436)
		35.5	0.03–0.002	437	$2.25 \times 10^{-3}$	(217)
		0–35	0.12–0.0005			(610, 611); cf. (61, 256, 378)
C <sub>5</sub> H <sub>8</sub> O <sub>3</sub> S <sub>2</sub>	Ethyl- $\alpha$ -dithiocarbonylglycolic acid	25	0.03–0.002	378	$2.12 \times 10^{-3}$	(285)
C <sub>5</sub> H <sub>8</sub> O <sub>3</sub> S <sub>2</sub>	Ethyl- $\beta$ -dithiocarbonylglycolic acid	25	0.06–0.001	378	$6.49 \times 10^{-4}$	(284)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub>	Dimethylmalonic acid.....	25	0.03–0.001	382	$7.5 \times 10^{-4}$	(390, 436, 577)
		0–65	0.12–0.0005			(526)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub>	Ethylmalonic acid.....	25	0.03–0.001	382	$1.23 \times 10^{-3}$	(436, 577)
		0–65	0.12–0.0005			(526)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub>	Glutaric acid.....	25	0.06–0.001	380	$4.67 \times 10^{-4}$	(86, 436, 524, 525.2, 565)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub>	Dimethyl malonate.....	25	0.016–0.008	(?)	$\Lambda_{0.016} = 0.52$	(213)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub>	Monoethyl malonate.....	25	0.12–0.004	380	$4.50 \times 10^{-4}$	(582)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub>	Pyrotartaric acid.....	25	0.03–0.0005	380	$8.5 \times 10^{-5}$	(95, 436, 561, 577); cf. (476)
		17–65	0.12–0.0005			(45, 48, 525, 609)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub>	Monomethyl succinate.....	25	0.05–0.0016	378	$3.25 \times 10^{-3}$	(100, 582)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub> S	Ethyl- $\beta$ -thiocarbonylglycolic acid...	25	0.06–0.002	380	$4.91 \times 10^{-4}$	(286)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub> S	Thioglycolhydracrylic acid.....	25	0.06–0.001	383	$2.5 \times 10^{-4}$	(357)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub> S	$\alpha$ -Thiolactylglycolic acid.....	25	0.06–0.001	383	$4.7 \times 10^{-4}$	(357)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub> S <sub>2</sub>	Methylenebisthioglycolic acid.....	25	0.06–0.002	381	$4.6 \times 10^{-4}$	(280)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub>	Monomethyl tartrate.....	25	0.03–0.001	378	$4.5 \times 10^{-4}$	(577)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub> S	$\alpha$ , $\alpha'$ -Methylethylsulfonedicarboxylic acid.....	25	0.06–0.001	382	$1.2 \times 10^{-3}$	(357)
C <sub>5</sub> H <sub>8</sub> O <sub>4</sub> S	$\beta$ , $\beta'$ -Methylethylsulfonedicarboxylic acid.....	25	0.06–0.001	382	$5.0 \times 10^{-3}$	(357)
C <sub>5</sub> H <sub>8</sub> O <sub>7</sub>	meso-Trihydroxyglutaric acid.....	25	0.02–0.01	378	$6.6 \times 10^{-4}$	(492)
C <sub>5</sub> H <sub>8</sub> O <sub>7</sub>	l-Trihydroxyglutaric acid.....	25	0.02–0.01	378	$1.30 \times 10^{-3}(2)$	(492)
C <sub>5</sub> H <sub>8</sub> O <sub>7</sub>	dl-Trihydroxyglutaric acid.....	25	0.02–0.01	378	$6.8 \times 10^{-4}$	(492)
C <sub>5</sub> H <sub>8</sub> O <sub>9</sub>	Leuconic acid.....	25	0.02–0.0006	(?)	$\Lambda_{0.02} = 51.6$	(127)
C <sub>5</sub> H <sub>7</sub> BrO <sub>2</sub>	$\delta$ -Bromovaleric acid.....	25	0.015	381	$1.9 \times 10^{-5}$	(344)
C <sub>5</sub> H <sub>7</sub> ClO <sub>2</sub>	$\delta$ -Chlorovaleric acid.....	25	0.03–0.001	381	$2.01 \times 10^{-5}$	(344)
C <sub>5</sub> H <sub>7</sub> IO <sub>2</sub>	$\delta$ -Iodovaleric acid.....	25	0.015	381	$1.7 \times 10^{-5}$	(344)
C <sub>5</sub> H <sub>7</sub> NO <sub>2</sub>	$\alpha$ -Oximinovaleic acid.....	25	0.06–0.001	382	$6.4 \times 10^{-4}$	(244, 291)
C <sub>5</sub> H <sub>7</sub> NO <sub>2</sub>	$\gamma$ -Oximinovaleic acid.....	25	0.03–0.001	382	$2.3 \times 10^{-5}$	(244)
C <sub>5</sub> H <sub>7</sub> NO <sub>2</sub>	$\alpha$ -Oximinovaleic acid.....	25	0.06–0.004	378	$1.14 \times 10^{-3}$	(265)
C <sub>5</sub> H <sub>7</sub> NO <sub>4</sub>	d-Aminoglutaric acid.....	25	0.03–0.001	378	$\Lambda_{0.03} = 10.3$	(44, 577)
C <sub>5</sub> H <sub>7</sub> NO <sub>4</sub>	dl-Aminoglutaric acid.....	25	0.03–0.001	378	$\Lambda_{0.03} = 10.2$	(570, 577)
C <sub>5</sub> H <sub>7</sub> NO <sub>4</sub>	Ethyl $\alpha$ -nitropropionate.....	0	0.03–0.007	246	$6.5 \times 10^{-7}$	(342, 498)
		25	0.03–0.007	383	$4 \times 10^{-7}$	(342, 498)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Methylethylacetic acid.....	25	0.12–0.001	381	$1.67 \times 10^{-5}$	(53, 558, 579)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Trimethylacetic acid.....	25	0.03–0.001	381	$9.6 \times 10^{-6}$	(458)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Valeric acid.....	25	0.06–0.001	381	$1.56 \times 10^{-5}$	(53, 163, 200, 436)
		10–40	0.25–0.001			(35, 293)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Isovaleric acid.....	25	0.25–0.001	381	$1.68 \times 10^{-5}$	(53, 163, 200, 558)
		0–65	0.12–0.0005			(610, 611)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	$\alpha$ -Ethoxypropionic acid.....	25	(?)	(?)	$2.46 \times 10^{-4}$	(438)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	$\beta$ -Ethoxypropionic acid.....	25	(?)	(?)	$3.19 \times 10^{-5}$	(438)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Hydroxytrimethylacetic acid.....	25	0.03–0.001	380	$1.37 \times 10^{-5}$	(386)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	$\alpha$ -Hydroxyvaleric acid.....	25	0.016–0.002	381	$1.30 \times 10^{-4}$	(378)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	$\gamma$ -Hydroxyvaleric acid.....	25	0.03–0.0009	381	$2.00 \times 10^{-5}$	(262)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	$\gamma$ -Methoxybutyric acid.....	25	(?)	(?)	$2.11 \times 10^{-5}$	(438)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	$\alpha$ -Methoxyisobutyric acid.....	25	(?)	(?)	$1.24 \times 10^{-4}$	(438)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	n-Propoxyacetic acid.....	25	(?)	(?)	$2.21 \times 10^{-4}$	(438)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Isopropoxyacetic acid.....	25	(?)	(?)	$2.03 \times 10^{-4}$	(438)
C <sub>5</sub> H <sub>10</sub> O <sub>5</sub>	Arabinose.....	25	0.5	(?)	$\Lambda_{0.5} = 0.25$	(71)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>0</sub> )	Lit.
Formula	Name					
C <sub>5</sub> H <sub>10</sub> O <sub>5</sub>	Xylose.....	25	0.5	(?)	Λ <sub>0.5</sub> = 0.46	(71)
C <sub>5</sub> H <sub>11</sub> N	Piperidine.....	25	0.12-0.004	234	1.25 × 10 <sup>-3</sup>	(104)
		0-50	0.06			(281)
C <sub>5</sub> H <sub>11</sub> NO <sub>2</sub> (+H <sub>2</sub> O)	Trimethylaminoacetic acid (beta-ine).....	25	0.06-0.004	(?)	Λ <sub>0.06</sub> = 1.75	(119)
C <sub>5</sub> H <sub>13</sub> CIN	Chloroamylamine.....	0	0.05-0.01	134	3.2 × 10 <sup>-4</sup>	(202)
C <sub>5</sub> H <sub>12</sub> O <sub>8</sub> S	Dimethyl-α-propionyl thetin.....	25	0.06-0.002	(?)	Λ <sub>0.06</sub> = 4.0	(119)
C <sub>5</sub> H <sub>12</sub> O <sub>4</sub>	Pentaerythritol.....	25	0.5-0.03	(?)	Λ <sub>0.06</sub> = 1.71	(82)
C <sub>5</sub> H <sub>13</sub> N	Isoamylamine.....	25	0.25-0.001	232	4.0 × 10 <sup>-4</sup>	(104); cf. (433)
C <sub>5</sub> H <sub>13</sub> N	Methyldiethylamine.....	25	0.12-0.004	234	2.2 × 10 <sup>-4</sup>	(104)
C <sub>5</sub> H <sub>13</sub> NO	Vinyltrimethylammonium hydroxide.....	25	0.06-0.004	241	Λ <sub>0.06</sub> = 216	(433)
C <sub>5</sub> H <sub>14</sub> N <sub>2</sub>	β-Methyltetramethylenediamine..	25	0.016-0.004	228	4.4 × 10 <sup>-4</sup>	(104)
C <sub>5</sub> H <sub>14</sub> N <sub>2</sub>	Pentamethylenediamine.....	25	0.06-0.004	228	6.0 × 10 <sup>-4</sup>	(104, 430)
C <sub>5</sub> HCl <sub>3</sub> O <sub>4</sub> H <sub>2</sub> O	Trichlorotetraketohexamethylene hydrate.....	25	0.016-0.001	380	Λ <sub>0.016</sub> = 337	(224)
C <sub>5</sub> H <sub>2</sub> BrCl <sub>3</sub> O <sub>4</sub> ·3H <sub>2</sub> O	Trichlorobromotriketohexamethylene trihydrate.....	25	0.008-0.002	(?)	Λ <sub>0.008</sub> = 3.3	(223)
C <sub>5</sub> H <sub>2</sub> Br <sub>2</sub> O <sub>4</sub>	Bromoanilic acid.....	25	0.008-0.0002	(?)	Λ <sub>0.008</sub> = 215	(406); cf. (196)
C <sub>5</sub> H <sub>2</sub> Cl <sub>2</sub> O <sub>4</sub>	Chloroanilic acid.....	25	0.008-0.0001	(?)	Λ <sub>0.008</sub> = 205	(406); cf. (196, 224)
C <sub>5</sub> H <sub>2</sub> Cl <sub>4</sub> O <sub>4</sub>	Tetrachlorodiketopentamethylenehydroxycarboxylic acid.....	[25]	0.04	(?)	Λ <sub>0.04</sub> = 415	(224)
C <sub>5</sub> H <sub>2</sub> N <sub>2</sub> O <sub>4</sub>	Nitroanilic acid.....	25	0.03-0.001	(?)	[Λ <sub>0.03</sub> = 679]	(224)
C <sub>5</sub> H <sub>2</sub> N <sub>4</sub> O <sub>4</sub>	Dinitrohydroxyphenylenefurazone	25	0.016-0.002	(?)	Λ <sub>0.016</sub> = 341	(455)
C <sub>5</sub> H <sub>2</sub> N <sub>4</sub> O <sub>4</sub>	1, 2-Dinitroso-3, 5-dinitrobenzene.	25	0.0005-0.0002	383	1.07 × 10 <sup>-4</sup>	(455)
C <sub>5</sub> H <sub>2</sub> O <sub>4</sub>	Rhodizonic acid.....	25	0.12-0.0001	(?)	Λ <sub>0.016</sub> = 106	(127)
C <sub>5</sub> H <sub>3</sub> Br <sub>3</sub> N <sub>2</sub> O	2, 4, 6-Tribromobenzenediazonium hydroxide.....	0	0.001-0.0005	132	[1.4 × 10 <sup>-5</sup> ]	(166); cf. (228)
C <sub>5</sub> H <sub>3</sub> Cl <sub>2</sub> NO <sub>2</sub>	4-Nitro-2, 6-dichlorophenol.....	25	0.003-0.0007	378	2.0 × 10 <sup>-4</sup>	(26)
C <sub>5</sub> H <sub>3</sub> Cl <sub>3</sub> O	2, 4, 6-Trichlorophenol.....	25	0.004-0.001	382	[1 × 10 <sup>-6</sup> ]	(226); cf. (229)
C <sub>5</sub> H <sub>3</sub> Cl <sub>3</sub> O <sub>4</sub>	Trichlorodiketopentamethylenehydroxycarboxylic acid.....	25	0.03-0.001	379	[6 × 10 <sup>-3</sup> ]	(224, 378)
C <sub>5</sub> H <sub>3</sub> N <sub>3</sub> O <sub>7</sub>	2, 4, 6-Trinitrophenol.....	25	0.05-0.0005	384.5	Λ <sub>0.016</sub> = 355	(208, 220.1, 314, 418); cf. (26, 132, 332, 434, 489, 505)
		0-90	0.05-0.0005			(162, 208, 299, 324, 525, 563, 564)
C <sub>5</sub> H <sub>3</sub> N <sub>3</sub> O <sub>4</sub>	2, 4, 6-Trinitroresorcinol.....	25	0.01-0.0013	379	Λ <sub>0.01</sub> = 354	(26)
C <sub>5</sub> H <sub>4</sub> Br <sub>2</sub> N <sub>2</sub> O	2, 4-Dibromobenzenediazonium hydroxide.....	0	0.004-0.002	135	1.35 × 10 <sup>-4</sup>	(166)
C <sub>5</sub> H <sub>4</sub> Br <sub>2</sub> NO <sub>2</sub> S	4, 5, 6-Tribromoaniline-2-sulfonic acid.....	25	0.005-0.0006	379	Λ <sub>0.005</sub> = 366	(436)
C <sub>5</sub> H <sub>4</sub> Br <sub>2</sub> NO <sub>2</sub> S	2, 4, 6-Tribromoaniline-3-sulfonic acid.....	25	0.009-0.001	379	Λ <sub>0.009</sub> = 352	(436)
C <sub>5</sub> H <sub>4</sub> Br <sub>2</sub> NO <sub>2</sub> S	2, 5, 6-Tribromoaniline-3-sulfonic acid.....	25	0.009-0.001	379	Λ <sub>0.009</sub> = 360	(436)
C <sub>5</sub> H <sub>4</sub> ClNO <sub>2</sub>	4-Nitro-2-chlorophenol.....	25	0.003-0.0007	379	1.8 × 10 <sup>-4</sup>	(26)
C <sub>5</sub> H <sub>4</sub> Cl <sub>2</sub> O	2, 4-Dichlorophenol.....	25	0.016-0.004	380	2 × 10 <sup>-8</sup>	(226)
C <sub>5</sub> H <sub>4</sub> FeN <sub>2</sub>	Ferrocyanic acid.....	25	0.12-0.00006	(?)	Λ <sub>0.02</sub> = 875	(432)
C <sub>5</sub> H <sub>4</sub> N <sub>2</sub> O <sub>8</sub> S	Diazobenzene-p-sulfonic acid.....	0	0.016	(?)	Λ <sub>0.016</sub> = 1.6	(203)
C <sub>5</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	2, 3-Dinitrophenol.....	25	0.004-0.001	380	1.3 × 10 <sup>-5</sup>	(278); cf. (26)
C <sub>5</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	2, 4-Dinitrophenol.....	25	0.004-0.001	380	9.6 × 10 <sup>-6</sup>	(278); cf. (26, 432)
C <sub>5</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	2, 5-Dinitrophenol.....	25	0.004-0.001	380	6.8 × 10 <sup>-6</sup>	(278); cf. (26)
C <sub>5</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	2, 6-Dinitrophenol.....	25	0.004-0.001	380	2.6 × 10 <sup>-4</sup>	(278); cf. (26)
C <sub>5</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	3, 4-Dinitrophenol.....	25	0.004-0.001	380	4.2 × 10 <sup>-6</sup>	(278); cf. (26)
C <sub>5</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	3, 5-Dinitrophenol.....	25	0.01-0.0025	380	2.0 × 10 <sup>-7</sup>	(278)
C <sub>5</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	2, 6-Dinitrohydroquinol.....	25	0.005-0.0006	378	7.0 × 10 <sup>-5</sup>	(26)
C <sub>5</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	3, 5-Dinitropyrocatechol.....	25	0.004-0.002	378	Λ <sub>0.004</sub> = 55.0	(66)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		$t, ^\circ\text{C}$	$c$ -Range	$\Lambda_0$	$k(\text{or } \Lambda_c)$	Lit.
Formula	Name					
$\text{C}_6\text{H}_4\text{O}_2$	Quinone.....	25	0.03	(?)	$\Lambda_{0.03} = 0.03$	(180)
$\text{C}_6\text{H}_4\text{O}_2\text{S}$	$\alpha$ -Thienylglyoxylic acid.....	25	0.03–0.001	383	$7.5 \times 10^{-2}$	(244)
$\text{C}_6\text{H}_4\text{O}_4$	Comanic acid.....	25	0.008–0.002	381	$2.7 \times 10^{-2}$	(446)
$\text{C}_6\text{H}_4\text{O}_6$	Comenic acid.....	25	0.004–0.003	381	$2 \times 10^{-2}$	(446)
$\text{C}_6\text{H}_3\text{AsCl}_2\text{O}_4$	Dichlorophenolarsonic acid.....	25	0.016–0.001	374	$5.5 \times 10^{-4}$	(356)
$\text{C}_6\text{H}_5\text{BrN}_3\text{O}$	$p$ -Bromobenzenediazonium hy- droxide.....	0	0.008–0.001	137	$1.48 \times 10^{-4}$	(166)
$\text{C}_6\text{H}_3\text{Br}_2\text{NO}_3\text{S}$	4, 5-Dibromoaniline-2-sulfonic acid	25	0.004–0.0009	379	$\Lambda_{0.004} = 360$	(102, 436)
$\text{C}_6\text{H}_3\text{Br}_2\text{NO}_3\text{S}$	4, 6-Dibromoaniline-2-sulfonic acid	25	0.009–0.001	379	$\Lambda_{0.009} = 360$	(102, 436)
$\text{C}_6\text{H}_3\text{Br}_2\text{NO}_3\text{S}$	4, 6-Dibromoaniline-3-sulfonic acid	25	0.014–0.0009	379	$\Lambda_{0.014} = 279$	(436)
$\text{C}_6\text{H}_3\text{Br}_2\text{NO}_3\text{S}$	2, 6-Dibromoaniline-4-sulfonic acid	25	0.016–0.0005	380	$\Lambda_{0.016} = 352$	(165)
$\text{C}_6\text{H}_5\text{ClO}$	$o$ -Chlorophenol.....	25	0.025–0.003	382	$[3.6 \times 10^{-3}]$	(26)
$\text{C}_6\text{H}_5\text{ClO}$	$p$ -Chlorophenol.....	25	0.016–0.002	382	$[2 \times 10^{-3}]$	(26)
$\text{C}_6\text{H}_3\text{Cl}_2\text{NO}_3\text{S}$	Dichloroaniline-3-sulfonic acid....	25	0.008–0.0005	379	$1.4 \times 10^{-3}$	(102, 165)
$\text{C}_6\text{H}_5\text{Cl}_3\text{O}_4$	Trichloro- $R$ -pentenedihydroxycar- boxylic acid.....	25	0.016–0.002	378	$8.5 \times 10^{-3}$	(223, 378)
$\text{C}_6\text{H}_5\text{NO}_2$	$p$ -Nitrosophenol.....	25	0.008–0.001	381	$7 \times 10^{-7}$	(557)
$\text{C}_6\text{H}_5\text{NO}_2$	Pyridine-2-carboxylic acid.....	25	0.016–0.001	383	$3 \times 10^{-7}$	(180)
$\text{C}_6\text{H}_5\text{NO}_2$	Pyridine-3-carboxylic acid.....	25	0.008–0.001	383	$5 \times 10^{-6}$	(436)
$\text{C}_6\text{H}_5\text{NO}_2$	Pyridine-4-carboxylic acid.....	25	0.008–0.001	383	$1.34 \times 10^{-5}$	(436)
$\text{C}_6\text{H}_5\text{NO}_3$	Comanamic acid.....	25	0.008–0.001	383	$1.07 \times 10^{-5}$	(436)
$\text{C}_6\text{H}_5\text{NO}_3$	$\alpha$ -Hydroxynicotinic acid.....	25	0.016–0.004	381	$2.65 \times 10^{-4}$	(446)
$\text{C}_6\text{H}_5\text{NO}_3$	$\alpha$ -Nitrophenol.....	25	0.008–0.001	383	$5 \times 10^{-6}$	(436)
$\text{C}_6\text{H}_5\text{NO}_3$		0	0.008–0.001	246	$5.6 \times 10^{-8}$	(226)
		18	(?)	(?)	$5.6 \times 10^{-8}$	(173)
		25	0.01–0.0005	382	$5.6 \times 10^{-8}$	(226); cf. (26, 201)
					$6.5 \times 10^{-8}$	(278); cf. (26, 201)
					$7.2 \times 10^{-8}$	(234); cf. (26, 201)
$\text{C}_6\text{H}_5\text{NO}_3$	$m$ -Nitrophenol.....	35	0.008–0.002	437	$8.0 \times 10^{-8}$	(226)
		10	0.033–0.016	297	$3.3 \times 10^{-9}$	(367)
		15	0.033–0.016	325	$3.9 \times 10^{-9}$	(367)
		25	0.033–0.001	382	$5.3 \times 10^{-9}$	(367); cf. (26, 201, 278)
		40	0.033–0.016	465	$7.6 \times 10^{-9}$	(367)
		50	0.033–0.016	516	$9.4 \times 10^{-9}$	(367)
$\text{C}_6\text{H}_5\text{NO}_3$	$p$ -Nitrophenol.....	0	0.03–0.002	246	$4.5 \times 10^{-8}$	(226)
		10	0.04–0.008	297	$4.5 \times 10^{-8}$	(363)
		15	0.04–0.008	325	$5.2 \times 10^{-8}$	(363)
		18	(?)	(?)	$5.8 \times 10^{-8}$	(173)
		25	0.03–0.002	382	$6.9 \times 10^{-8}$	(226, 278, 363); cf. (26, 201, 234)
		35	0.03–0.004	437	$9 \times 10^{-8}$	(?)
		40	0.04–0.008	465	$1.02 \times 10^{-7}$	(363)
		50	0.04–0.008	516	$1.26 \times 10^{-7}$	(363)
$\text{C}_6\text{H}_5\text{NO}_3$	2-( $\alpha$ )-Pyrrolyglyoxylic acid.....	25	0.016–0.001	383	$[9.5 \times 10^{-7}]$	(7)
$\text{C}_6\text{H}_5\text{NO}_3\text{S}$	Thienyl- $\text{syn}$ -ketoximecarboxylic acid.....	25	0.016–0.001	378	$4.95 \times 10^{-3}$	(244)
$\text{C}_6\text{H}_5\text{NO}_4$	Comenamic acid.....	25	0.002–0.0005	380	$2.4 \times 10^{-4}$	(446)
$\text{C}_6\text{H}_5\text{NO}_4$	2-Nitroresorcinol.....	25	0.003–0.0008	379	$1.3 \times 10^{-5}$	(26)
$\text{C}_6\text{H}_5\text{NO}_4$	4-Nitroresorcinol.....	25	0.008–0.001	379	$1.1 \times 10^{-5}$	(26, 66)
$\text{C}_6\text{H}_5\text{NO}_5\text{S}$	2-Methylthiazole-4, 5-dicarboxylic acid.....	25	0.01–0.0025	382	$6.5 \times 10^{-2}$	(49)
$\text{C}_6\text{H}_5\text{NO}_5\text{S}$	$m$ -Nitrobenzenesulfonic acid.....	25	0.03–0.001	(?)	$\Lambda_{0.03} = 348$	(434)
		0–65	0.03–0.0005			(6, 10, 511)
$\text{C}_6\text{H}_5\text{N}_3\text{O}_3$	$p$ -Nitrobenzenediazonium hydrox- ide.....	0	0.016–0.002	139	$[8 \times 10^{-3}]$	(166)
$\text{C}_6\text{H}_5\text{N}_3\text{O}_4$	2-Amino-4, 6-dinitrophenol.....	25	0.002–0.0005	377	$4.8 \times 10^{-5}$	(526)
		0–65	0.002–0.0005			(526)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>6</sub> H <sub>4</sub> AsNO <sub>2</sub>	<i>o</i> -Nitrophenylarsonic acid.....	25	0.016-0.001	373	3.5 × 10 <sup>-4</sup>	(185, 355)
C <sub>6</sub> H <sub>4</sub> AsNO <sub>2</sub>	<i>m</i> -Nitrophenylarsonic acid.....	25	0.016-0.001	373	1.32 × 10 <sup>-4</sup>	(356)
C <sub>6</sub> H <sub>4</sub> AsNO <sub>2</sub>	<i>p</i> -Nitrophenylarsonic acid.....	25	0.016-0.001	374	1.37 × 10 <sup>-4</sup>	(355)
C <sub>6</sub> H <sub>4</sub> AsNO <sub>2</sub>	3-Nitro-4-hydroxyphenylarsonic acid.....	25	0.016-0.001	373	8.1 × 10 <sup>-4</sup>	(356)
C <sub>6</sub> H <sub>4</sub> BrNO <sub>2</sub> S	2-Bromoaniline-5-sulfonic acid....	25	0.014-0.0009	380	1 × 10 <sup>-3</sup>	(102, 436)
C <sub>6</sub> H <sub>4</sub> BrNO <sub>2</sub> S	4-Bromoaniline-2-sulfonic acid....	25	0.016-0.001	380	1.6 × 10 <sup>-3</sup>	(436)
C <sub>6</sub> H <sub>4</sub> BrNO <sub>2</sub> S	4-Bromoaniline-3-sulfonic acid....	25	0.016-0.001	380	7.1 × 10 <sup>-4</sup>	(102, 436)
C <sub>6</sub> H <sub>4</sub> ClNO <sub>2</sub> S	4-Amino-2-chlorophenolsulfonic acid.....	25	0.008-0.001	378	8.05 × 10 <sup>-4</sup>	(165)
C <sub>6</sub> H <sub>4</sub> I NO <sub>2</sub> S	4-Iodoaniline-2-sulfonic acid.....	25	0.008-0.001	380	Λ <sub>0.008</sub> = 289.6	(102)
C <sub>6</sub> H <sub>4</sub> I NO <sub>2</sub> S	5-Iodoaniline-2-sulfonic acid.....	25	0.008-0.001	380	Λ <sub>0.008</sub> = 309.5	(102)
C <sub>6</sub> H <sub>4</sub> I NO <sub>2</sub> S	6-Iodoaniline-2-sulfonic acid.....	25	0.016-0.001	380	Λ <sub>0.016</sub> = 340	(102)
C <sub>6</sub> H <sub>4</sub> I NO <sub>2</sub> S	4-Iodoaniline-3-sulfonic acid.....	25	0.016-0.001	380	7.0 × 10 <sup>-4</sup>	(102)
C <sub>6</sub> H <sub>4</sub> I NO <sub>2</sub> S	5-Iodoaniline-3-sulfonic acid.....	25	0.016-0.001	380	2.0 × 10 <sup>-3</sup>	(102)
C <sub>6</sub> H <sub>4</sub> I NO <sub>2</sub> S	6-Iodoaniline-3-sulfonic acid.....	25	0.016-0.008	380	Λ <sub>0.016</sub> = 242	(102)
C <sub>6</sub> H <sub>4</sub> I NO <sub>2</sub> S	2-Iodoaniline-4-sulfonic acid.....	25	0.03-0.001	380	Λ <sub>0.03</sub> = 267	(102)
C <sub>6</sub> H <sub>4</sub> I NO <sub>2</sub> S	3-Iodoaniline-4-sulfonic acid.....	25	0.004-0.001	380	Λ <sub>0.004</sub> = 228	(102)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O	Benzenediazonium hydroxide.....	0	0.03-0.002	142	1.21 = 10 <sup>-3</sup>	(144)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	<i>o</i> -Quinonedioxime.....	25	0.002-0.001	380	1.8 × 10 <sup>-7</sup>	(238)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	<i>p</i> -Quinonedioxime.....	25	0.00125	(?)	Λ <sub>0.00125</sub> = 0.25	(180)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	<i>o</i> -Diazophenol.....	25	0.03-0.016	(?)	Λ <sub>0.03</sub> = 0.9	(236)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	<i>p</i> -Diazophenol.....	25	0.03-0.016	(?)	Λ <sub>0.03</sub> = 1.4	(236)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	Phenylnitroamine.....	1	0.02-0.001	250	1.2 × 10 <sup>-6</sup>	(171)
		10	0.002-0.001	298	1.5 × 10 <sup>-6</sup>	(171)
		18	0.02-0.001	340	1.7 × 10 <sup>-6</sup>	(171)
		25	0.008-0.001	378	2.2 × 10 <sup>-6</sup>	(227); cf. (31)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	Phenylnitrosohydroxylamine.....	0	0.008-0.002	246	4 × 10 <sup>-6</sup>	(227)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	2-Amino-4-nitrophenol.....	25	0.005-0.0012	379	2.5 × 10 <sup>-7</sup>	(26)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	Dimethylalloxan.....	25	0.03-0.001	(?)	Λ <sub>0.03</sub> = 8.0	(557)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub> S	Benzenesulfonitroamide.....	0	0.025-0.003	(?)	Λ <sub>0.025</sub> = 228	(43)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub> S	3-Nitroaniline-6-sulfonic acid.....	25	0.016-0.002	381	8 × 10 <sup>-3</sup>	(165)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O	6-Methyl-2, 3-triazo-4-hydroxy-7, O''-pyridazine.....	25	0.004-0.001	379	1.7 × 10 <sup>-6</sup>	(114)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	<i>N</i> -Dicyanodisuccinamide.....	25	0.006-0.0008	376	3 × 10 <sup>-6</sup>	(26)
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	<i>α</i> -Methyluric acid.....	[25]	0.00027	(?)	2 × 10 <sup>-6</sup>	(52)
C <sub>6</sub> H <sub>4</sub> O	Phenol.....	18	0.1	340	1.3 × 10 <sup>-10</sup>	(589)
		25	0.12-0.03	383	1.06 × 10 <sup>-10</sup>	(311); cf. (26, 82, 226)
C <sub>6</sub> H <sub>4</sub> O <sub>2</sub>	Hydroquinol.....	25	0.5-0.06	383	Λ <sub>0.06</sub> = 0.013	(82); cf. (26)
C <sub>6</sub> H <sub>4</sub> O <sub>2</sub>	Pyrocatechol.....	25	0.12-0.03	383	3.2 × 10 <sup>-10</sup>	(82, 441); cf. (26)
C <sub>6</sub> H <sub>4</sub> O <sub>2</sub>	Resorcinol.....	0	0.12-0.03	247	3 × 10 <sup>-7</sup>	(82, 226); cf. (26)
		25	0.12-0.03	383	6 × 10 <sup>-7</sup>	(82, 226); cf. (26)
		40	0.03-0.008	464	3.5 × 10 <sup>-6</sup>	(82, 226); cf. (26)
C <sub>6</sub> H <sub>4</sub> O <sub>2</sub> S	Benzenesulfinic acid.....	18	0.03-0.002	342	Λ <sub>0.03</sub> = 222	(15)
		25	0.03-0.001	382	Λ <sub>0.03</sub> = 242	(15)
		30	0.03-0.001	410	Λ <sub>0.03</sub> = 249	(15)
C <sub>6</sub> H <sub>4</sub> O <sub>2</sub>	1, 2, 4-Trihydroxybenzene.....	25	0.25	381	Λ <sub>0.025</sub> = 0.32	(66)
C <sub>6</sub> H <sub>4</sub> O <sub>2</sub>	Phloroglucinol.....	25	0.12-0.008	381	Λ <sub>0.06</sub> = 0.06	(82); cf. (26)
C <sub>6</sub> H <sub>4</sub> O <sub>2</sub>	Pyrogallol.....	25	1.0-0.005	381	Λ <sub>0.06</sub> = 0.056	(26, 82, 376)
C <sub>6</sub> H <sub>4</sub> O <sub>2</sub> S	Benzenesulfonic acid.....	25	0.03-0.001	(?)	Λ <sub>0.03</sub> = 348	(434)
		0-65	0.12-0.0005			(610, 611)
C <sub>6</sub> H <sub>4</sub> O <sub>4</sub>	<i>sym.</i> -Methyltrimethenyldicarboxylic acid.....	25	0.016-0.001	382	5.75 × 10 <sup>-4</sup>	(183)
C <sub>6</sub> H <sub>4</sub> O <sub>4</sub> S	Phenolsulfonic acid.....	0	0.06-0.0003	(?)	Λ <sub>0.06</sub> = 173	(387)
C <sub>6</sub> H <sub>4</sub> O <sub>4</sub>	Aconitic acid.....	25	0.04-0.001	378	1.33 × 10 <sup>-3</sup>	(577)
		0-35	0.04-0.0005		1.54 × 10 <sup>-3</sup>	(582)
						(45, 525)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Lambda_0$	<i>k</i> (or $\Lambda_c$ )	Lit.
Formula	Name					
C <sub>6</sub> H <sub>6</sub> O <sub>6</sub>	Trimethylene-1, 1, 2-tricarboxylic acid.....	25	0.03–0.008	377	$8.8 \times 10^{-3}$	(578)
C <sub>6</sub> H <sub>6</sub> O <sub>6</sub> S <sub>2</sub>	Benzene-1, 2-disulfonic acid.....	25	0.125–0.0005	380	$\Lambda_{0.01} = 341$	(164)
C <sub>6</sub> H <sub>6</sub> O <sub>6</sub> S <sub>2</sub>	Benzene-1, 3-disulfonic acid.....	25	0.125–0.002	380	$\Lambda_{0.03} = 359$	(164)
C <sub>6</sub> H <sub>6</sub> O <sub>6</sub> S <sub>2</sub>	Benzene-1, 4-disulfonic acid.....	25	0.125–0.001	380	$\Lambda_{0.03} = 361$	(164)
C <sub>6</sub> H <sub>6</sub> O <sub>7</sub> S <sub>2</sub>	Phenoldisulfonic acid.....	0	0.06–0.0003	(?)	$\Lambda_{0.06} = 322$	(337)
C <sub>6</sub> H <sub>6</sub> O <sub>10</sub> S <sub>3</sub>	Phenoltrisulfonic acid.....	0	0.06–0.0003	(?)	$\Lambda_{0.06} = 470$	(387)
C <sub>6</sub> H <sub>7</sub> AsN <sub>2</sub> O <sub>6</sub>	2-Nitro-4-aminophenylarsonic acid	25	0.004–0.002	372	$8.4 \times 10^{-5}$	(355)
C <sub>6</sub> H <sub>7</sub> AsN <sub>2</sub> O <sub>6</sub>	3-Nitro-4-aminophenylarsonic acid	25	0.016–0.001	372	$3.2 \times 10^{-4}$	(356)
C <sub>6</sub> H <sub>7</sub> AsO <sub>3</sub>	Phenylarsonic acid.....	25	0.016–0.001	375	$2.5 \times 10^{-4}$	(185, 355)
C <sub>6</sub> H <sub>7</sub> AsO <sub>4</sub>	<i>p</i> -Hydroxyphenylarsonic acid.....	25	0.016–0.001	375	$1.5 \times 10^{-4}$	(355)
C <sub>6</sub> H <sub>7</sub> AsO <sub>6</sub>	Resorcinolarsonic acid.....	25	0.016–0.001	374	$6.2 \times 10^{-5}$	(356)
C <sub>6</sub> H <sub>7</sub> BO <sub>2</sub>	Phenylboric acid.....	25	0.125	(?)	$\Lambda_{0.125} = 0.13$	(538)
C <sub>6</sub> H <sub>7</sub> N	Aniline.....	25	0.3–0.002	(?)	$\Lambda_{0.02} = 0.17$	(103); cf. (44)
C <sub>6</sub> H <sub>7</sub> N	$\alpha$ -Picoline.....	25	0.09–0.003	237	$[4 \times 10^{-8}]$	(207)
C <sub>6</sub> H <sub>7</sub> NO <sub>2</sub> S	Benzenesulfoneamide.....	0	0.016	(?)	$\Lambda_{0.016} = 0.17$	(222)
		25	0.03–0.001	(?)	$\Lambda_{0.03} = 0.98$	(504)
C <sub>6</sub> H <sub>7</sub> NO <sub>2</sub> S	2, 4-Dimethylthiazole-5-carboxylic acid.....	25	0.004–0.0005	382	$1.15 \times 10^{-4}$	(49)
C <sub>6</sub> H <sub>7</sub> NO <sub>3</sub>	Methyl cyanoacetoacetate.....	25	0.016–0.001	382	$8.2 \times 10^{-4}$	(213)
C <sub>6</sub> H <sub>7</sub> NO <sub>3</sub> S	<i>o</i> -Anilinesulfonic acid.....	25	0.016–0.001	382	$3.25 \times 10^{-3}$	(102, 436)
		0–35	0.03–0.0005			(525)
C <sub>6</sub> H <sub>7</sub> NO <sub>3</sub> S	<i>m</i> -Anilinesulfonic acid.....	25	0.016–0.001	382	$1.82 \times 10^{-4}$	(102, 436)
		0–65	0.03–0.0005			(525, 609)
C <sub>6</sub> H <sub>7</sub> NO <sub>3</sub> S	<i>p</i> -Anilinesulfonic acid.....	25	0.03–0.001	382	$5.70 \times 10^{-4}$	(102, 436)
					$6.10 \times 10^{-4}$	(622)
		0–65	0.03–0.0005			(525, 608, 609)
C <sub>6</sub> H <sub>7</sub> NO <sub>4</sub> S	2-Aminophenol-4-sulfonic acid.....	25	0.016–0.0005	379	$9.25 \times 10^{-5}$	(102, 165)
C <sub>6</sub> H <sub>7</sub> NO <sub>4</sub> S	4-Aminophenol-2-sulfonic acid.....	25	0.004–0.001	379	$8.15 \times 10^{-5}$	(102, 165)
C <sub>6</sub> H <sub>7</sub> N <sub>2</sub> O <sub>4</sub>	Dimethylvioluric acid.....	25	0.03–0.002	378	$1.55 \times 10^{-5}$	(379)
C <sub>6</sub> H <sub>7</sub> N <sub>2</sub> O <sub>6</sub>	Dimethylnitrobarbituric acid.....	24.5	0.03–0.001	376	$\Lambda_{0.03} = 334$	(276)
C <sub>6</sub> H <sub>8</sub> AsNO <sub>2</sub>	Arsanilic acid.....	25	0.016–0.001	373	$5.7 \times 10^{-5}$	(185, 356)
C <sub>6</sub> H <sub>8</sub> AsNO <sub>4</sub>	3-Hydroxy-4-aminophenylarsonic acid.....	25	0.002–0.001	373	$7 \times 10^{-5}$	(355)
C <sub>6</sub> H <sub>8</sub> As <sub>2</sub> O <sub>6</sub>	<i>p</i> -Phenylenediarsonic acid.....	25	0.016–0.001	372	$2.6 \times 10^{-3}$	(356)
C <sub>6</sub> H <sub>8</sub> N <sub>2</sub> O <sub>2</sub>	Propyl cyanonitrosoacetate.....	25	0.016–0.001	379	$2.28 \times 10^{-5}$	(410)
C <sub>6</sub> H <sub>8</sub> N <sub>2</sub> O <sub>3</sub>	5, 5-Dimethylbarbituric acid.....	25	0.016	381	$7.2 \times 10^{-8}$	(624)
C <sub>6</sub> H <sub>8</sub> N <sub>2</sub> O <sub>3</sub>	5-Ethylbarbituric acid.....	25	0.016	381	$3.8 \times 10^{-6}$	(624)
C <sub>6</sub> H <sub>8</sub> N <sub>2</sub> O <sub>3</sub> S	$\alpha$ -Phenylenediamine-3-sulfonic acid	25	0.02–0.0007	378	$4.8 \times 10^{-5}$	(436)
C <sub>6</sub> H <sub>8</sub> O <sub>2</sub>	Dihydroresorcinol.....	25	0.06–0.001	380	$5.5 \times 10^{-6}$	(508)
C <sub>6</sub> H <sub>8</sub> O <sub>2</sub>	Sorbic acid.....	25	0.008–0.001	382	$1.70 \times 10^{-3}$	(436)
C <sub>6</sub> H <sub>8</sub> O <sub>2</sub>	Hydroxymethyleneacetylacetone..	2.6	0.03–0.004	257	$1.7 \times 10^{-6}$	(124)
C <sub>6</sub> H <sub>8</sub> O <sub>2</sub>	Pentic acid.....	25	0.03–0.001	380	$8.6 \times 10^{-5}$	(569)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Allylmalonic acid.....	25	0.03–0.001	382	$1.51 \times 10^{-3}$	(577)
		0–65	0.12–0.0005			(526)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	$\Delta\alpha$ , $\beta$ -Dihydromuconic acid.....	25	0.015–0.0001	380	$[2 \times 10^{-4}]$	(524)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	$\Delta\beta$ , $\gamma$ -Dihydromuconic acid.....	25	0.016–0.001	380	$1.00 \times 10^{-4}$	(524); cf. (493)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Dimethylmaleic acid.....	25	0.016–0.001	380	$1.1 \times 10^{-4}$	(577)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Ethylfumaric acid.....	25	0.03–0.001	380	$9.2 \times 10^{-4}$	(569, 577)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Ethylmaleic acid.....	25	0.03–0.001	380	$2.31 \times 10^{-3}$	(577)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Tetramethylene-1, 1-dicarboxylic acid.....	25	0.06–0.001	380	$8.17 \times 10^{-4}$	(582); cf. (524, 534)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Monoethyl fumarate.....	25	0.05–0.0014	378	$4.73 \times 10^{-4}$	(582)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Monoethyl maleate.....	25	0.02–0.0012	378	$1.1 \times 10^{-3}$	(582)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	$\alpha$ -Monomethyl mesaconate.....	25	0.03–0.001	381	$3.49 \times 10^{-4}$	(9)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	$\beta$ -Monomethyl mesaconate.....	25	0.03–0.001	379	$5.05 \times 10^{-4}$	(9)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	$\alpha$ -Methyleneglutaric acid.....	25	0.06–0.001	380	$6.7 \times 10^{-5}$	(186)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	<i>cis</i> - $\beta$ -Methylglutaconic acid.....	25	0.06–0.001	379	$1.28 \times 10^{-4}$	(192)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	<i>trans</i> - $\beta$ -Methylglutaconic acid.....	25	0.06–0.001	379	$1.38 \times 10^{-4}$	(192)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Methylitaconic acid.....	25	0.03–0.001	380	$9.3 \times 10^{-4}$	(55, 170, 577)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	<i>cis</i> -Tetramethylene-1, 2-dicarboxylic acid.....	25	(?)	380	$6.6 \times 10^{-5}$	(447)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	<i>trans</i> -Tetramethylene-1, 2-dicarboxylic acid.....	25	(?)	380	2.8 × 10 <sup>-4</sup>	(447)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	<i>L</i> -Acetylmalic acid.....	25	0.06-0.001	378	2.35 × 10 <sup>-3</sup>	(283)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Propenyltricarboxylic acid.....	25	0.03-0.001	378	2.99 × 10 <sup>-3</sup>	(578)
C <sub>6</sub> H <sub>8</sub> O <sub>4</sub>	Tricarballic acid.....	25	0.06-0.001	378	2.15 × 10 <sup>-4</sup>	(24, 98, 578, 582)
		0-65	0.12-0.0005			(45, 610, 611)
C <sub>6</sub> H <sub>8</sub> O <sub>7</sub>	Citric acid.....	25	0.06-0.001	378	8.0 × 10 <sup>-4</sup>	(578, 582)
		0-65	0.12-0.0005			(45, 159, 198, 211, 353, 395, 472, 525, 609)
C <sub>6</sub> H <sub>8</sub> O <sub>7</sub>	<i>d</i> -Saccharolactonic acid.....	25.1	0.12-0.001	380	1.3 × 10 <sup>-3</sup>	(398)
C <sub>6</sub> H <sub>8</sub> AsN <sub>2</sub> O <sub>3</sub>	<i>o</i> -Phenylenediaminearsonic acid...	25	0.016-0.001	372	2.3 × 10 <sup>-4</sup>	(356)
C <sub>6</sub> H <sub>8</sub> BrO <sub>4</sub>	<i>α</i> -Ethylbromosuccinic acid.....	25	0.03-0.002	381	4.1 × 10 <sup>-3</sup>	(577)
C <sub>6</sub> H <sub>8</sub> BrO <sub>4</sub>	<i>β</i> -Ethylbromosuccinic acid.....	25	0.03-0.002	381	5.2 × 10 <sup>-3</sup>	(577)
C <sub>6</sub> H <sub>8</sub> NO	Methylpyridinium hydroxide.....	25	0.03-0.004	(?)	Λ <sub>0.03</sub> = 213	(241)
C <sub>6</sub> H <sub>8</sub> NO <sub>4</sub>	Ethyl isonitrosoacetoacetate.....	0	0.06-0.016	247	4.1 × 10 <sup>-8</sup>	(411)
		18	0.06-0.016	350	7.3 × 10 <sup>-8</sup>	(411)
		25	0.06-0.016	388	8.7 × 10 <sup>-8</sup>	(411, 498)
		35	0.06-0.016	447	1.1 × 10 <sup>-7</sup>	(411)
		40	0.06-0.016	476	1.2 × 10 <sup>-7</sup>	(411)
C <sub>6</sub> H <sub>8</sub> NO <sub>4</sub>	Monoethyl <i>α</i> -oximinosuccinate....	25	0.03-0.001	380	1.88 × 10 <sup>-4</sup>	(244)
C <sub>6</sub> H <sub>8</sub> NO <sub>4</sub>	Monoethyl <i>β</i> -oximinosuccinate....	25	0.03-0.008	380	5.2 × 10 <sup>-3</sup>	(244)
C <sub>6</sub> H <sub>8</sub> N <sub>2</sub> O <sub>2</sub>	Histidine.....	25	0.03-0.001	(?)	Λ <sub>0.03</sub> = 3.7	(304)
C <sub>6</sub> H <sub>8</sub> N <sub>2</sub> O <sub>2</sub>	<i>C</i> -Methyl- <i>N</i> -ethylosotriazolecarboxylic acid.....	20	0.004	(?)	Λ <sub>0.004</sub> = 77.9	(429)
		0-40	0.004			(429)
C <sub>6</sub> H <sub>10</sub> N <sub>2</sub> O	Isovaleryl cyanamide.....	25	0.02-0.0007	376	1.36 × 10 <sup>-4</sup>	(26)
C <sub>6</sub> H <sub>10</sub> N <sub>2</sub> O <sub>4</sub>	<i>β, β</i> -Dinitrocaproic acid.....	25	0.008-0.0005	376	6.84 × 10 <sup>-4</sup>	(436)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	Divinylglycol.....	25	0.75-0.5	(?)	Λ <sub>0.5</sub> = 0.024	(65)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>α, β</i> -Hexenic acid.....	25	0.06-0.001	380	1.88 × 10 <sup>-5</sup>	(190)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>β, γ</i> -Hexenic acid.....	25	0.06-0.001	380	2.63 × 10 <sup>-5</sup>	(190); cf. (436)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>γ, δ</i> -Hexenic acid.....	25	0.06-0.001	380	1.73 × 10 <sup>-5</sup>	(190)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>δ, ε</i> -Hexenic acid.....	25	0.06-0.001	380	1.90 × 10 <sup>-5</sup>	(190)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>α</i> -Methyl- <i>α, β</i> -pentenic acid.....	25	0.06-0.008	380	1.05 × 10 <sup>-5</sup>	(190, 436)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>α</i> -Methyl- <i>β, γ</i> -pentenic acid.....	25	0.06-0.001	380	2.99 × 10 <sup>-5</sup>	(190)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>α</i> -Methyl- <i>γ, δ</i> -pentenic acid.....	25	0.06-0.001	380	2.15 × 10 <sup>-5</sup>	(190)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>β</i> -Methyl- <i>α, β</i> -pentenic acid.....	25	0.03-0.001	380	7.5 × 10 <sup>-5</sup>	(187)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>β</i> -Methyl- <i>β, γ</i> -pentenic acid.....	25	0.06-0.001	380	3.0 × 10 <sup>-5</sup>	(187)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	Pentamethylenecarboxylic acid....	25	0.05-0.0012	378	1.20 × 10 <sup>-4</sup>	(525.2, 635)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	Trimethylacrylic acid.....	25	0.009-0.0005	379	3.8 × 10 <sup>-5</sup>	(550)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	Ethyl acetoacetate.....	1	0.06-0.001	247	1.6 × 10 <sup>-8</sup>	(431)
		25	0.06-0.001	383	4.4 × 10 <sup>-8</sup>	(431); cf. (213, 569)
		35	0.06-0.001	441	5.3 × 10 <sup>-8</sup>	(431)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>γ</i> -Acetobutyric acid.....	25	0.06-0.0005	379	2.16 × 10 <sup>-5</sup>	(508)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	<i>β</i> -Acetoisobutyric acid.....	25	(?)	(?)	3.03 × 10 <sup>-5</sup>	(61)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	Trimethylpyruvic acid.....	25	1.0-0.016	378	3.4 × 10 <sup>-3</sup>	(83)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Adipic acid.....	25	0.03-0.001	378	3.63 × 10 <sup>-5</sup>	(138, 436, 524, 565)
					3.25 × 10 <sup>-5</sup>	(86)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	<i>asym.</i> -Dimethylsuccinic acid.....	25	0.03-0.0005	379	7.8 × 10 <sup>-5</sup>	(20, 49, 95, 451, 577)
					8.2 × 10 <sup>-5</sup>	(561)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	<i>sym.</i> - <i>anti</i> -Dimethylsuccinic acid ..	25	0.03-0.001	379	1.36 × 10 <sup>-4</sup>	(139)
					1.20 × 10 <sup>-4</sup>	(95, 577, 631)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	<i>sym.</i> - <i>p</i> -Dimethylsuccinic acid.....	25	0.03-0.0006	379	1.28 × 10 <sup>-4</sup>	(84); cf. (561)
					2.04 × 10 <sup>-4</sup>	(49, 139); cf. (561)
					1.87 × 10 <sup>-4</sup>	(84, 95, 451, 577, 631)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Ethylsuccinic acid.....	25	0.03-0.001	379	8.3 × 10 <sup>-5</sup>	(49, 577)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Methylethylmalonic acid.....	25	0.09-0.0007	380	1.61 × 10 <sup>-5</sup>	(49, 577)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Lambda_0$	<i>k</i> (or $\Lambda_c$ )	Lit.
Formula	Name					
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Methylethylmalonic acid.—(Cont'd)	0–65	0.12–0.0005			(526)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	$\alpha$ -Methylglutaric acid.....	25	0.03–0.001	378	$5.2 \times 10^{-5}$	(49, 391, 577)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	$\beta$ -Methylglutaric acid.....	25	0.03–0.001	378	$5.9 \times 10^{-5}$	(525.2, 577)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Propylmalonic acid.....	25	0.06–0.001	382	$1.09 \times 10^{-3}$	(49, 390, 577)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Isopropylmalonic acid.....	25	0.07–0.001	382	$1.24 \times 10^{-3}$	(49, 390, 577)
		0–65	0.03–0.0005			(526)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Monomethyl pyrotartaric acid....	25	0.05–0.006	377	$3.85 \times 10^{-5}$	(100)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Monoethyl succinate.....	25	0.05–0.002	376	$3.01 \times 10^{-5}$	(582)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Monoethyl isosuccinate.....	25	0.06–0.002	376	$3.85 \times 10^{-4}$	(582)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> S	$\alpha$ -Thiodilactylic acid ( $\alpha$ -modifi- cation).....	25	0.06–0.001	382	$4.9 \times 10^{-4}$	(357)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> S	$\alpha$ -Thiodilactylic acid ( $\beta$ -modifi- cation).....	25	0.06–0.001	382	$4.3 \times 10^{-4}$	(357)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> S	$\beta$ -Thiodilactylic acid.....	25	0.06–0.001	382	$7.7 \times 10^{-5}$	(357)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> S	Thio- $\alpha$ -lactylhydracrylic acid.....	25	0.06–0.001	382	$2.1 \times 10^{-4}$	(357)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> S <sub>2</sub>	$\alpha$ -Dithiodilactylic acid.....	25	0.06–0.001	382	$8.9 \times 10^{-4}$	(357)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> S <sub>2</sub>	$\beta$ -Dithiodilactylic acid.....	25	0.004–0.001	382	$8.9 \times 10^{-5}$	(357)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> S <sub>2</sub>	Ethylenethioglycolic acid.....	25	0.06–0.001	382	$4.0 \times 10^{-4}$	(552)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> S <sub>3</sub>	$\alpha$ -Trithiodilactylic acid.....	25	0.06–0.001	382	$7.9 \times 10^{-4}$	(357)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> Se	Selenodilactylic acid ( <i>a</i> acid, M. P., 145°).....	25	0.02–0.0007	376	$4.2 \times 10^{-4}$	(134)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub> Se	Selenodilactylic acid ( <i>b</i> acid, M. P., 109°).....	25	0.02–0.0007	376	$3.8 \times 10^{-4}$	(134)
C <sub>6</sub> H <sub>10</sub> O <sub>5</sub>	Saccharic acid anhydride.....	25	0.03–0.008	382	$1.2 \times 10^{-6}$	(569)
C <sub>6</sub> H <sub>10</sub> O <sub>5</sub>	Isosaccharic acid anhydride.....	25	0.03–0.008	382	$1.7 \times 10^{-6}$	(569)
C <sub>6</sub> H <sub>10</sub> O <sub>6</sub> S	$\alpha$ , $\alpha'$ -Diethylsulfonedicarboxylic acid.....	25	0.06–0.001	383	$1.01 \times 10^{-2}$	(357, 359)
C <sub>6</sub> H <sub>10</sub> O <sub>6</sub> S	$\beta$ , $\beta'$ -Diethylsulfonedicarboxylic acid.....	25	0.008–0.001	383	$2.3 \times 10^{-4}$	(357)
C <sub>6</sub> H <sub>10</sub> O <sub>6</sub> S <sub>2</sub>	Ethylenesulfoxyacetic acid.....	25	0.03–0.001	380	$\Lambda_{0.03} = 151$	(552)
C <sub>6</sub> H <sub>10</sub> O <sub>8</sub>	Mucic acid.....	25	0.016–0.001	378	$6.1 \times 10^{-4}$	(378)
C <sub>6</sub> H <sub>10</sub> O <sub>8</sub>	<i>d</i> -Saccharic acid.....	25.2	0.12–0.001	380	$1.0 \times 10^{-3}$	(398); cf. (432)
C <sub>6</sub> H <sub>10</sub> O <sub>8</sub> S <sub>2</sub>	Ethylenesulfoneacetic acid.....	25	0.016–0.001	380	$\Lambda_{0.016} = 253$	(552)
C <sub>6</sub> H <sub>11</sub> NO <sub>3</sub>	$\alpha$ -Oximinoisohexoic acid.....	25	0.06–0.004	377	$5.5 \times 10^{-4}$	(265)
C <sub>6</sub> H <sub>11</sub> NO <sub>3</sub>	$\alpha$ -Oximino- <i>n</i> -hexoic acid.....	25	0.03–0.008	377	$6.5 \times 10^{-4}$	(265)
C <sub>6</sub> H <sub>11</sub> NO <sub>4</sub>	$\beta$ -Monoethyl aminosuccinate.....	25	0.013–0.0008	378	$6.7 \times 10^{-6}$	(601)
C <sub>6</sub> H <sub>11</sub> NO <sub>4</sub>	Ethylaminosuccinic acid.....	25	0.03–0.001	378	$3.39 \times 10^{-4}$	(371)
C <sub>6</sub> H <sub>11</sub> NO <sub>4</sub>	Nitrocaproic acid.....	25	0.016–0.0005	378	$1.20 \times 10^{-4}$	(436)
C <sub>6</sub> H <sub>11</sub> N <sub>3</sub> O <sub>4</sub>	Ethyl 4-methyl-1, 2-dihydroxy-1, 2, 5-triazole-3-carboxylate.....	18	0.04–0.008	342	$6.1 \times 10^{-3}$	(174)
C <sub>6</sub> H <sub>11</sub> O <sub>7</sub> P	Mannide phosphoric acid.....	25	0.125–0.002	381	$\Lambda_{0.125} = 208$	(120)
C <sub>6</sub> H <sub>12</sub> Hg <sub>3</sub> O <sub>8</sub>	Trimercurydiacetone hydroxide....	18	0.004–0.002	(?)	$\Lambda_{0.004} = 0.02$	(18)
C <sub>6</sub> H <sub>12</sub> N <sub>4</sub>	Hexamethylenetetramine.....	[18]	0.5–0.03	199	$1.5 \times 10^{-8}$	(462)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Isobutylacetic acid.....	25	0.03–0.001	378	$1.47 \times 10^{-5}$	(53, 200)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Caproic acid.....	25	0.04–0.001	379	$1.40 \times 10^{-5}$	(53, 163, 200, 436)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Isocaproic acid.....	25	0.04–0.002	379	$1.45 \times 10^{-5}$	(163)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Cyclohexane-1, 2-diol (M. P. 99°).....	25	1.0–0.5	(?)	$\Lambda_{1.0} = 0.012$	(74)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Cyclohexane-1, 2-diol (M. P. 104°).....	25	1.0–0.5	(?)	$\Lambda_{1.0} = 0.004$	(74)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Diethylacetic acid.....	25	0.03–0.0008	379	$1.98 \times 10^{-5}$	(53, 525.2, 579)
					$1.85 \times 10^{-5}$	(200, 558)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Dimethylethylacetic acid.....	25	0.03–0.001	379	$9.1 \times 10^{-6}$	(53)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Isobutoxyacetic acid.....	25	(?)	(?)	$2.14 \times 10^{-4}$	(438)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	<i>n</i> -Butoxyacetic acid.....	25	(?)	(?)	$2.19 \times 10^{-4}$	(438)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	$\gamma$ -Ethoxybutyric acid.....	25	(?)	(?)	$2.00 \times 10^{-5}$	(438)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	$\alpha$ -Hydroxy- $\alpha$ , $\beta$ , $\beta$ -trimethylpro- pionic acid.....	[25]	(?)	(?)	$1.13 \times 10^{-4}$	(448)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	$\beta$ -Hydroxy- $\alpha$ , $\beta$ , $\beta$ -trimethylpro- pionic acid.....	25	0.05–0.0016	377	$3.4 \times 10^{-5}$	(448, 550)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	$\delta$ -Methoxyvaleric acid.....	25	(?)	(?)	$1.91 \times 10^{-5}$	(438)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Paracetaldehyde.....	15	0.5–0.016	(?)	$\Lambda_{0.03} = 0.7$	(554)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Trimethylethylenelactic acid.....	25	0.03–0.001	377	$2.1 \times 10^{-5}$	(550)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Rhamnose.....	25	0.5	(?)	$\Lambda_{0.5} = 0.10$	(71)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>6</sub> H <sub>12</sub> O <sub>6</sub>	Fructose.....	20	0.4	(?)	Λ <sub>0.4</sub> = 0.05	(71, 349, 473)
C <sub>6</sub> H <sub>12</sub> O <sub>6</sub>	Galactose.....	25	1.0	(?)	Λ <sub>1.0</sub> = 0.035	(117)
C <sub>6</sub> H <sub>12</sub> O <sub>6</sub>	Glucose.....	20	0.4–0.1	(?)	Λ <sub>0.4</sub> = 0.13	(71, 349, 464, 473)
C <sub>6</sub> H <sub>12</sub> O <sub>6</sub>	Mannose.....	25	0.5	(?)	Λ <sub>0.5</sub> = 0.63	(71)
C <sub>6</sub> H <sub>12</sub> O <sub>7</sub>	Gluconic acid.....	25	0.5–0.03	376	2.5 × 10 <sup>-4</sup>	(85)
C <sub>6</sub> H <sub>14</sub> O <sub>2</sub>	Pinacol.....	25	0.25–0.03	(?)	Λ <sub>0.25</sub> = 0.06	(65)
C <sub>6</sub> H <sub>14</sub> O <sub>3</sub> S	Diethylthetin.....	25	0.06–0.004	(?)	Λ <sub>0.06</sub> = 2.15	(119)
C <sub>6</sub> H <sub>14</sub> O <sub>3</sub> S	Ethylidimethylthetin.....	25	0.06–0.004	(?)	Λ <sub>0.06</sub> = 2.6	(119)
C <sub>6</sub> H <sub>14</sub> O <sub>3</sub> Se	Diethylselenetin.....	25	0.06–0.002	(?)	Λ <sub>0.06</sub> = 6.3	(119)
C <sub>6</sub> H <sub>14</sub> O <sub>6</sub>	d-Mannitol.....	25	0.03	(?)	Λ <sub>0.03</sub> = 0.17	(479)
C <sub>6</sub> H <sub>14</sub> O <sub>6</sub>	Sorbitol.....	25	2–0.06	(?)	Λ <sub>0.5</sub> = 0.03	(65)
C <sub>6</sub> H <sub>15</sub> N	Dipropylamine.....	25	0.12–0.004	228	8.2 × 10 <sup>-4</sup>	(104)
C <sub>6</sub> H <sub>15</sub> N	Triethylamine.....	25	0.12–0.004	231	5.2 × 10 <sup>-4</sup>	(104)
		0–50	0.06			(251, 433)
C <sub>6</sub> H <sub>15</sub> O <sub>4</sub> P	Dipropyl phosphate.....	25	0.125–0.001	381	Λ <sub>0.03</sub> = 297	(164)
C <sub>6</sub> H <sub>15</sub> OPb	Lead triethyl hydroxide.....	25	0.07–0.01	(?)	Λ <sub>0.07</sub> = 3.8	(509)
C <sub>6</sub> H <sub>15</sub> OS	Triethylsulfonium hydroxide.....	25	0.06–0.004	234	Λ <sub>0.06</sub> = 210	(433)
C <sub>6</sub> H <sub>15</sub> OSn	Tin triethyl hydroxide.....	25	0.07–0.004	(?)	Λ <sub>0.07</sub> = 0.29	(509)
C <sub>7</sub> H <sub>3</sub> Br <sub>3</sub> O <sub>2</sub>	2, 4, 6-Tribromobenzoic acid.....	25	0.008–0.001	380	3.8 × 10 <sup>-2</sup>	(598)
C <sub>7</sub> H <sub>4</sub> BrClO <sub>3</sub>	3-Hydroxy-2-chloro-6-bromobenzoic acid.....	25	0.007–0.0009	380	2.2 × 10 <sup>-2</sup>	(135)
C <sub>7</sub> H <sub>4</sub> BrClO <sub>3</sub>	3-Hydroxy-6-chloro-2-bromobenzoic acid.....	25	0.008–0.001	380	1.95 × 10 <sup>-3</sup>	(135)
C <sub>7</sub> H <sub>4</sub> BrNO <sub>4</sub>	2-Nitro-3-bromobenzoic acid.....	25	0.001	377	3.2 × 10 <sup>-3</sup>	(279)
C <sub>7</sub> H <sub>4</sub> BrNO <sub>4</sub>	3-Nitro-2-bromobenzoic acid.....	25	0.004–0.001	377	1.05 × 10 <sup>-3</sup>	(279)
C <sub>7</sub> H <sub>4</sub> BrNO <sub>4</sub>	3-Nitro-4-bromobenzoic acid.....	25	0.0014–0.0007	377	4.2 × 10 <sup>-4</sup>	(323)
C <sub>7</sub> H <sub>4</sub> BrNO <sub>4</sub>	5-Nitro-2-bromobenzoic acid.....	25	0.004–0.001	377	8.5 × 10 <sup>-3</sup>	(279)
C <sub>7</sub> H <sub>4</sub> BrNO <sub>4</sub>	6-Nitro-3-bromobenzoic acid.....	25	0.008–0.001	377	1.35 × 10 <sup>-3</sup>	(279, 436)
C <sub>7</sub> H <sub>4</sub> Br <sub>2</sub> O <sub>2</sub>	2, 4-Dibromobenzoic acid.....	25	0.0025–0.0006	380	2.0 × 10 <sup>-3</sup>	(323)
C <sub>7</sub> H <sub>4</sub> Br <sub>2</sub> O <sub>4</sub>	Dibromogallie acid.....	25	0.03–0.001	378	1.17 × 10 <sup>-2</sup>	(436)
C <sub>7</sub> H <sub>4</sub> ClNO <sub>4</sub>	2-Nitro-3-chlorobenzoic acid.....	25	0.002–0.001	380	4.0 × 10 <sup>-3</sup>	(279)
C <sub>7</sub> H <sub>4</sub> ClNO <sub>4</sub>	2-Nitro-4-chlorobenzoic acid.....	25	0.004–0.002	380	9.0 × 10 <sup>-3</sup>	(49)
C <sub>7</sub> H <sub>4</sub> ClNO <sub>4</sub>	3-Nitro-2-chlorobenzoic acid.....	25	0.004–0.001	380	8.1 × 10 <sup>-3</sup>	(279)
C <sub>7</sub> H <sub>4</sub> ClNO <sub>4</sub>	3-Nitro-4-chlorobenzoic acid.....	25	0.003–0.0006	380	4.4 × 10 <sup>-4</sup>	(49, 490)
C <sub>7</sub> H <sub>4</sub> ClNO <sub>4</sub>	3-Nitro-5-chlorobenzoic acid.....	25	0.002–0.0003	380	7.41 × 10 <sup>-4</sup>	(313)
C <sub>7</sub> H <sub>4</sub> ClNO <sub>4</sub>	4-Nitro-2-chlorobenzoic acid.....	25	0.03–0.002	380	9.9 × 10 <sup>-3</sup>	(49)
C <sub>7</sub> H <sub>4</sub> ClNO <sub>4</sub>	5-Nitro-2-chlorobenzoic acid.....	25	0.01–0.001	380	6.0 × 10 <sup>-3</sup>	(49, 279)
C <sub>7</sub> H <sub>4</sub> ClNO <sub>4</sub>	6-Nitro-3-chlorobenzoic acid.....	25	0.014–0.001	380	1.35 × 10 <sup>-2</sup>	(49, 279)
C <sub>7</sub> H <sub>4</sub> Cl <sub>2</sub> O <sub>3</sub>	2-Hydroxy-3, 5-dichlorobenzoic acid.....	25	0.0016–0.0008	380	4.5 × 10 <sup>-3</sup>	(135)
C <sub>7</sub> H <sub>4</sub> Cl <sub>2</sub> O <sub>3</sub>	3-Hydroxy-2, 6-dichlorobenzoic acid.....	25	0.008–0.001	380	2.1 × 10 <sup>-2</sup>	(135)
C <sub>7</sub> H <sub>4</sub> Cl <sub>2</sub> O <sub>4</sub>	3, 4-Dihydroxy-2, 5-dichlorobenzoic acid.....	25	0.03–0.001	380	Λ <sub>0.03</sub> = 49.6	(135)
C <sub>7</sub> H <sub>4</sub> Cl <sub>2</sub> O <sub>4</sub>	3, 4-Dihydroxy-5, 6-dichlorobenzoic acid.....	25	0.016–0.001	380	Λ <sub>0.016</sub> = 75.2	(135)
C <sub>7</sub> H <sub>4</sub> FNO <sub>4</sub>	3-Nitro-4-fluorobenzoic acid.....	25	(?)	(?)	4.33 × 10 <sup>-4</sup>	(490)
C <sub>7</sub> H <sub>4</sub> N <sub>2</sub> O <sub>6</sub>	2, 3-Dinitrobenzoic acid.....	25	0.01–0.0006	380	1.3 × 10 <sup>-2</sup>	(518)
		40	0.01–0.0006			(518)
C <sub>7</sub> H <sub>4</sub> N <sub>2</sub> O <sub>6</sub>	2, 4-Dinitrobenzoic acid.....	25	0.01–0.0006	380	3.5 × 10 <sup>-2</sup>	(518)
		0–65	0.03–0.0005			(518, 610, 611)
C <sub>7</sub> H <sub>4</sub> N <sub>2</sub> O <sub>6</sub>	2, 5-Dinitrobenzoic acid.....	25	0.01–0.0006	380	2.4 × 10 <sup>-2</sup>	(518)
		40	0.01–0.0006			(518)
C <sub>7</sub> H <sub>4</sub> N <sub>2</sub> O <sub>6</sub>	2, 6-Dinitrobenzoic acid.....	25	0.01–0.0006	380	[Λ <sub>0.01</sub> = 339]	(518)
		40	0.01–0.0006			(518)
C <sub>7</sub> H <sub>4</sub> N <sub>2</sub> O <sub>6</sub>	3, 4-Dinitrobenzoic acid.....	25	0.01–0.0006	380	1.59 × 10 <sup>-2</sup>	(518)
		40	0.01–0.0006			(518)
C <sub>7</sub> H <sub>4</sub> N <sub>2</sub> O <sub>6</sub>	3, 5-Dinitrobenzoic acid.....	25	0.01–0.0001	380	1.55 × 10 <sup>-2</sup>	(312); cf. (49, 518)
		0–65	0.01–0.0005			(518, 610, 611)
C <sub>7</sub> H <sub>4</sub> O <sub>4</sub>	Chelidonic acid.....	25	0.016–0.0005	(?)	Λ <sub>0.016</sub> = 455	(436)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	$\Lambda_0$	k (or $\Lambda_c$ )	Lit.
Formula	Name					
C <sub>7</sub> H <sub>4</sub> O <sub>7</sub>	Meconic acid.....	25	0.03-0.0001	(?)	$\Lambda_{0.01} = 450$	(378, 436)
		0-65	0.03-0.0005			(610, 611)
C <sub>7</sub> H <sub>5</sub> BrO <sub>2</sub>	<i>o</i> -Bromobenzoic acid.....	25	0.008-0.001	383	$1.42 \times 10^{-3}$	(436)
		0-35	0.008-0.0005			(525)
C <sub>7</sub> H <sub>5</sub> BrO <sub>2</sub>	<i>m</i> -Bromobenzoic acid.....	25	0.002-0.001	383	$1.35 \times 10^{-4}$	(436)
		0-35	0.002-0.005			(525)
C <sub>7</sub> H <sub>5</sub> BrO <sub>2</sub>	2-Hydroxy-5-bromobenzoic acid...	25	0.004-0.0002	381	$2.40 \times 10^{-3}$	(313)
C <sub>7</sub> H <sub>5</sub> BrO <sub>4</sub>	2, 4-Dihydroxy-?-bromobenzoic acid.....	25	0.002-0.0002	380	$1.03 \times 10^{-3}$	(313)
C <sub>7</sub> H <sub>5</sub> BrO <sub>4</sub>	2, 5-Dihydroxy-?-bromobenzoic acid.....	25	0.008-0.0002	380	$3.90 \times 10^{-3}$	(313)
C <sub>7</sub> H <sub>5</sub> BrO <sub>5</sub>	Bromogallic acid.....	25	0.016-0.001	378	$5.8 \times 10^{-4}$	(436)
C <sub>7</sub> H <sub>5</sub> Br <sub>2</sub> NO <sub>2</sub>	3, 4-Dibromo-1-methyl-pyrrylglyoxylic acid.....	25	0.004-0.001	380	[ $\Lambda_{0.001} = 367$ ]	(7)
C <sub>7</sub> H <sub>5</sub> ClO <sub>2</sub>	<i>o</i> -Chlorobenzoic acid.....	25	0.016-0.0002	382.5	$1.28 \times 10^{-3}$	(312, 436)
		0-99	0.008-0.0005			(506, 610, 611)
C <sub>7</sub> H <sub>5</sub> ClO <sub>2</sub>	<i>m</i> -Chlorobenzoic acid.....	25	0.004-0.001	383	$1.52 \times 10^{-4}$	(436)
		0-35	0.002-0.0005			(525)
C <sub>7</sub> H <sub>5</sub> ClO <sub>2</sub>	<i>p</i> -Chlorobenzoic acid.....	25	0.0005	383	$9.1 \times 10^{-5}$	(436)
		0-35	0.0005			(525)
C <sub>7</sub> H <sub>5</sub> ClO <sub>3</sub>	2-Hydroxy-5-chlorobenzoic acid...	25	0.003-0.0008	381	$1.95 \times 10^{-3}$	(135)
C <sub>7</sub> H <sub>5</sub> ClO <sub>3</sub>	3-Hydroxy-2-chlorobenzoic acid...	25	0.004-0.001	381	$1.36 \times 10^{-3}$	(135)
C <sub>7</sub> H <sub>5</sub> ClO <sub>3</sub>	3-Hydroxy-6-chlorobenzoic acid...	25	0.016-0.001	381	$1.38 \times 10^{-3}$	(135)
C <sub>7</sub> H <sub>5</sub> ClO <sub>3</sub>	4-Hydroxy-3-chlorobenzoic acid...	25	0.008-0.001	381	$5.6 \times 10^{-5}$	(135)
C <sub>7</sub> H <sub>5</sub> FO <sub>2</sub>	<i>o</i> -Fluorobenzoic acid.....	25	0.004-0.001	382	$3.15 \times 10^{-4}$	(521)
C <sub>7</sub> H <sub>5</sub> FO <sub>2</sub>	<i>m</i> -Fluorobenzoic acid.....	25	0.016-0.001	382	$1.34 \times 10^{-4}$	(436, 521)
C <sub>7</sub> H <sub>5</sub> FO <sub>2</sub>	<i>p</i> -Fluorobenzoic acid.....	25	0.004-0.001	382	$1.35 \times 10^{-4}$	(521); cf (490)
C <sub>7</sub> H <sub>5</sub> IO <sub>2</sub>	<i>o</i> -Iodobenzoic acid.....	25	0.006-0.0008	382	$1.29 \times 10^{-3}$	(14)
		25-99	0.002-0.001			(506)
C <sub>7</sub> H <sub>5</sub> IO <sub>2</sub>	<i>m</i> -Iodobenzoic acid.....	25	0.0008-0.0004	382	$1.6 \times 10^{-4}$	(49)
		60-99	0.002-0.0014			(506)
C <sub>7</sub> H <sub>5</sub> IO <sub>3</sub>	<i>o</i> -Iodosobenzoic acid.....	25	0.004-0.001	382	$6 \times 10^{-7}$	(14)
C <sub>7</sub> H <sub>5</sub> NO	<i>p</i> -Cyanophenol.....	0	0.03-0.004	240	$3 \times 10^{-7}$	(226)
		25	0.03-0.004	383	$6 \times 10^{-7}$	(226)
		35	0.03-0.004	438	$8 \times 10^{-7}$	(226)
C <sub>7</sub> H <sub>5</sub> NO <sub>2</sub> S	<i>o</i> -Benzoic sulfimide (saccharin)...	25	0.006-0.0016	380	$3.7 \times 10^{-3}$	(255)
		36.5	0.4-0.00003			(374)
C <sub>7</sub> H <sub>5</sub> NO <sub>4</sub>	<i>o</i> -Nitrobenzoic acid.....	10	0.03-0.006	297	$8.2 \times 10^{-3}$	(425)
		15	0.03-0.006	326	$7.6 \times 10^{-3}$	(425)
		20	0.04-0.009	354	$7.1 \times 10^{-3}$	(425)
		25	0.03-0.0002	382	$6.4 \times 10^{-3}$	(312, 425, 436)
		30	0.04-0.01	410	$5.9 \times 10^{-3}$	(425)
		0-99	0.03-0.0005			(172, 299, 506, 611)
C <sub>7</sub> H <sub>5</sub> NO <sub>4</sub>	<i>m</i> -Nitrobenzoic acid.....	0	0.01-0.0016	244	$2.76 \times 10^{-4}$	(172)
		20	0.01-0.0016	353	$3.09 \times 10^{-4}$	(172)
		25	0.016-0.001	381	$3.16 \times 10^{-4}$	(172)
					$3.38 \times 10^{-4}$	(436)
		30	0.01-0.0016	410	$3.16 \times 10^{-4}$	(172)
		35	0.01-0.0016	438	$3.14 \times 10^{-4}$	(172)
		40	0.01-0.0016	464	$3.14 \times 10^{-4}$	(172)
		45	0.01-0.0016	487	$3.14 \times 10^{-4}$	(172)
		50	0.01-0.0016	510	$3.13 \times 10^{-4}$	(172)
		0-99	0.008-0.0005			(299, 506, 611)
C <sub>7</sub> H <sub>5</sub> NO <sub>4</sub>	<i>p</i> -Nitrobenzoic acid.....	25	0.004-0.001	381	$3.88 \times 10^{-4}$	(436)
		0-65	0.002-0.0005			(610, 611)
C <sub>7</sub> H <sub>5</sub> NO <sub>4</sub>	Pyridine-2, 3-dicarboxylic acid....	25	0.016-0.004	381	$2.95 \times 10^{-3}$	(436)
C <sub>7</sub> H <sub>5</sub> NO <sub>4</sub>	Pyridine-2, 4-dicarboxylic acid....	25	0.008-0.002	381	$5.8 \times 10^{-3}$	(436, 556)
C <sub>7</sub> H <sub>5</sub> NO <sub>4</sub>	Pyridine-2, 5-dicarboxylic acid....	25	0.008-0.001	381	$4.1 \times 10^{-3}$	(436)
C <sub>7</sub> H <sub>5</sub> NO <sub>4</sub>	Pyridine-2, 6-dicarboxylic acid....	25	0.016-0.0005	381	$5.6 \times 10^{-3}$	(556)
C <sub>7</sub> H <sub>5</sub> NO <sub>4</sub>	Pyridine-3, 4-dicarboxylic acid....	25	0.008-0.001	381	$2.05 \times 10^{-3}$	(436)
C <sub>7</sub> H <sub>5</sub> NO <sub>4</sub>	Pyridine-3, 5-dicarboxylic acid....	25	0.004-0.0005	381	$1.45 \times 10^{-3}$	(436)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>7</sub> H <sub>5</sub> NO <sub>5</sub>	Ammonchelidonic acid.....	25	0.006–0.0007	(?)	Λ <sub>0.006</sub> = 391	(436)
C <sub>7</sub> H <sub>5</sub> NO <sub>5</sub>	α-Hydroxyisocinchomeric acid..	25	0.008–0.001	381	1.60 × 10 <sup>-2</sup>	(436)
C <sub>7</sub> H <sub>5</sub> NO <sub>5</sub>	3-Nitro-2-hydroxybenzoic acid....	25	0.008–0.001	381	1.5 × 10 <sup>-2</sup>	(378, 436)
C <sub>7</sub> H <sub>5</sub> NO <sub>5</sub>	5-Nitro-2-hydroxybenzoic acid....	25	0.004–0.001	381	7.8 × 10 <sup>-3</sup>	(378); cf. (436)
C <sub>7</sub> H <sub>5</sub> N <sub>3</sub> O <sub>7</sub>	2, 4, 6-Trinitro- <i>m</i> -cresol.....	25	0.008	382	Λ <sub>0.008</sub> = 352	(314)
C <sub>7</sub> H <sub>6</sub> BrNO <sub>2</sub>	<i>n</i> - <i>p</i> -Bromophenylnitromethane....	0	0.0004	(?)	[Λ <sub>0.0004</sub> = 2.5]	(249)
C <sub>7</sub> H <sub>6</sub> BrNO <sub>2</sub>	Iso- <i>p</i> -bromophenylnitromethane....	0	0.003	(?)	Λ <sub>0.003</sub> = 24	(249)
C <sub>7</sub> H <sub>6</sub> ClNO <sub>2</sub>	3-Amino-2-chlorobenzoic acid....	25	0.016–0.001	378	6 × 10 <sup>-4</sup>	(277)
C <sub>7</sub> H <sub>6</sub> ClNO <sub>2</sub>	3-Amino-6-chlorobenzoic acid....	25	0.016–0.001	378	7 × 10 <sup>-5</sup>	(32)
C <sub>7</sub> H <sub>6</sub> N <sub>2</sub> O <sub>3</sub> S	Benzenesulfonecyanamide.....	25	0.009–0.001	376	1.27 × 10 <sup>-5</sup>	(26)
C <sub>7</sub> H <sub>6</sub> N <sub>2</sub> O <sub>4</sub>	3-Amino-5-nitrobenzoic acid....	25	0.01–0.0004	380	2.0 × 10 <sup>-4</sup>	(49)
C <sub>7</sub> H <sub>6</sub> N <sub>2</sub> O <sub>4</sub>	<i>m</i> -Nitrophenylnitromethane (NO <sub>2</sub> .C <sub>6</sub> H <sub>4</sub> .CH.NO.OH).....	25	0.003–0.0025	(?)	[Λ <sub>0.0025</sub> = 70]	(342); cf. (275)
C <sub>7</sub> H <sub>6</sub> N <sub>2</sub> O <sub>4</sub>	<i>m</i> -Nitrophenylnitromethane (NO <sub>2</sub> .C <sub>6</sub> H <sub>4</sub> .CH <sub>2</sub> .NO <sub>2</sub> ).....	25	0.0016	(?)	Λ <sub>0.0016</sub> = 6	(342)
C <sub>7</sub> H <sub>6</sub> O <sub>2</sub>	Benzoic acid.....	0	0.001–0.001	244	5.7 × 10 <sup>-4</sup>	(172)
		20	0.02–0.001	353	6.16 × 10 <sup>-4</sup>	(172)
		25	0.02–0.001	383	5.86 × 10 <sup>-4</sup>	(436)
					6.15 × 10 <sup>-4</sup>	(172); cf. (376, 451, 457, 528)
		30	0.02–0.001	410	6.14 × 10 <sup>-4</sup>	(172)
		35	0.02–0.001	438	6.14 × 10 <sup>-4</sup>	(172)
		40	0.02–0.001	464	6.12 × 10 <sup>-4</sup>	(172)
		45	0.02–0.001	487	6.09 × 10 <sup>-4</sup>	(172)
		50	0.02–0.001	511	6.05 × 10 <sup>-4</sup>	(172)
		0–99	0.06–0.0005			(45, 47, 126, 178, 273, 328, 506, 609)
						(204); cf. (441)
C <sub>7</sub> H <sub>6</sub> O <sub>2</sub>	Salicylaldehyde.....	25	0.03–0.004	383	1.53 × 10 <sup>-6</sup>	(204)
C <sub>7</sub> H <sub>6</sub> O <sub>2</sub>	<i>m</i> -Hydroxybenzaldehyde.....	25	0.06–0.016	383	3.5 × 10 <sup>-6</sup>	(441)
C <sub>7</sub> H <sub>6</sub> O <sub>2</sub>	<i>p</i> -Hydroxybenzaldehyde.....	25	0.06–0.002	383	1.0 × 10 <sup>-6</sup>	(204)
					1.63 × 10 <sup>-6</sup>	(441)
C <sub>7</sub> H <sub>6</sub> O <sub>3</sub>	2, 4-Dihydroxybenzaldehyde.....	25	0.008–0.001	381	2.2 × 10 <sup>-6</sup>	(204)
C <sub>7</sub> H <sub>6</sub> O <sub>3</sub>	2, 5-Dihydroxybenzaldehyde.....	25	0.008–0.001	381	3.52 × 10 <sup>-6</sup>	(204)
C <sub>7</sub> H <sub>6</sub> O <sub>3</sub>	3, 4-Dihydroxybenzaldehyde.....	25	0.12–0.0002	381	4.2 × 10 <sup>-6</sup>	(204)
					3.05 × 10 <sup>-6</sup>	(441)
C <sub>7</sub> H <sub>6</sub> O <sub>3</sub>	<i>allo</i> -Furfuracrylic acid.....	(?)	(?)	(?)	2.8 × 10 <sup>-6</sup>	(346)
C <sub>7</sub> H <sub>6</sub> O <sub>3</sub>	Furfuracrylic acid.....	(?)	(?)	(?)	7.82 × 10 <sup>-6</sup>	(346)
C <sub>7</sub> H <sub>6</sub> O <sub>3</sub>	Salicylic acid.....	0	0.01–0.0016	245	3.25 × 10 <sup>-6</sup>	(172)
		20	0.01–0.0016	354	7.7 × 10 <sup>-4</sup>	(172)
		25	0.014–0.001	384	9.5 × 10 <sup>-4</sup>	(81, 102.1, 172, 313, 376, 436)
		35	0.01–0.0016	439	1.00 × 10 <sup>-5</sup>	(102.1, 172)
		40	0.01–0.0016	465	1.00 × 10 <sup>-5</sup>	(172)
		45	0.01–0.0016	488	1.01 × 10 <sup>-5</sup>	(172)
		50	0.01–0.0016	512	1.01 × 10 <sup>-5</sup>	(172)
		0–99	0.016–0.0005			(45, 47, 126, 506, 526, 609)
C <sub>7</sub> H <sub>6</sub> O <sub>3</sub>	<i>m</i> -Hydroxybenzoic acid.....	0	0.01–0.0016	244	7.1 × 10 <sup>-5</sup>	(172)
		20	0.01–0.0016	353	7.61 × 10 <sup>-5</sup>	(172)
		25	0.03–0.001	383	8.54 × 10 <sup>-5</sup>	(436)
					7.74 × 10 <sup>-5</sup>	(81, 172)
		30	0.01–0.0016	410	7.65 × 10 <sup>-5</sup>	(172)
		35	0.01–0.0016	438	7.60 × 10 <sup>-5</sup>	(172)
		40	0.01–0.0016	464	7.52 × 10 <sup>-5</sup>	(172)
		45	0.01–0.0016	487	7.45 × 10 <sup>-5</sup>	(172)
		50	0.01–0.0016	511	7.38 × 10 <sup>-5</sup>	(172)
		0–65	0.03–0.0005			(45, 47, 378, 525, 609, 611)
						(81, 341, 436); cf. (378)
C <sub>7</sub> H <sub>6</sub> O <sub>3</sub>	<i>p</i> -Hydroxybenzoic acid.....	25	0.03–0.001	384	2.80 × 10 <sup>-5</sup>	(45, 47, 609, 611)
		0–65	0.016–0.0005			



C-Table.—The C-Arrangement.—(Continued)

Formu	Electrolyte	$t, ^\circ\text{C}$	$\alpha$ -Range	$\Delta_0$	$k(\text{or } \Delta_c)$	Lit.
$\text{C}_7\text{H}_5\text{O}_4$	2, 3-Dihydroxybenzoic acid.....	25	0.016-0.0005	383	$1.12 \times 10^{-3}$	(436)
$\text{C}_7\text{H}_5\text{O}_4$	2, 4-Dihydroxybenzoic acid.....	25	0.016-0.0005	383	$5.05 \times 10^{-4}$	(81, 313, 436, 540)
$\text{C}_7\text{H}_5\text{O}_4$	2, 5-Dihydroxybenzoic acid.....	0-65 25	0.008-0.0005 0.016-0.0005	383	$1.06 \times 10^{-3}$	(610, 611) (81, 313, 436)
$\text{C}_7\text{H}_5\text{O}_4$	2, 6-Dihydroxybenzoic acid.....	0-35 25	0.008-0.0005 0.016-0.001	383	$5 \times 10^{-3}$	(610) (436)
$\text{C}_7\text{H}_5\text{O}_4$	3, 4-Dihydroxybenzoic acid.....	25	0.03-0.001	383	$3.1 \times 10^{-6}$	(66, 378, 436)
$\text{C}_7\text{H}_5\text{O}_4$	3, 5-Dihydroxybenzoic acid.....	25	0.03-0.001	383	$8.9 \times 10^{-6}$	(436)
$\text{C}_7\text{H}_5\text{O}_4$	Gallic aldehyde.....	19.8	0.016	(?)	$\Delta_{0.016} = 1.25$	(484)
$\text{C}_7\text{H}_5\text{O}_4$	Hydroxyhydroquinol aldehyde.....	25	0.008-0.001	381	$1.77 \times 10^{-6}$	(204)
$\text{C}_7\text{H}_5\text{O}_4$	Phloroglucinol aldehyde.....	25	0.007-0.0008	381	$4.25 \times 10^{-6}$	(204)
$\text{C}_7\text{H}_5\text{O}_4$	Pyrogallol aldehyde.....	25	0.004-0.0005	381	$1.12 \times 10^{-4}$	(204)
$\text{C}_7\text{H}_5\text{O}_4$	Gallic acid.....	25	0.03-0.001	383	$3.8 \times 10^{-5}$ $3.4 \times 10^{-5}$	(436) (376)
$\text{C}_7\text{H}_5\text{O}_4$	Phloroglucinolcarboxylic acid.....	0-65 25	0.016-0.0005 0.03-0.001	383	$1.9 \times 10^{-3}$	(66, 525, 609) (436)
$\text{C}_7\text{H}_5\text{O}_4$	Pyrogallolcarboxylic acid.....	25	0.016-0.001	383	$5.3 \times 10^{-4}$	(378, 436)
$\text{C}_7\text{H}_5\text{O}_4\text{S}$	<i>o</i> -Sulfobenzoic acid.....	25	0.03-0.0005	[379]	$\Delta_{0.03} = 376$	(525)
$\text{C}_7\text{H}_5\text{O}_4\text{S}$	<i>m</i> -Sulfobenzoic acid.....	0-35 25	0.03-0.0005 0.09-0.0014	379	$\Delta_{0.09} = 324$	(525) (598)
$\text{C}_7\text{H}_5\text{O}_4\text{S}$	<i>p</i> -Sulfobenzoic acid.....	0-35 25	0.002-0.0005 0.015-0.0004	382	$\Delta_{0.015} = 375.5$	(525) (601)
$\text{C}_7\text{H}_5\text{O}_4\text{S}$	5-Sulfosalicylic acid.....	25	0.03-0.0005	(?)	$\Delta_{0.03} = 355$	(526)
$\text{C}_7\text{H}_7\text{Br}_2\text{NO}_2\text{S}$	3, 5-Dibromo-2-toluidine-4-sulfonic acid.....	0-65 25	0.03-0.0005 0.016-0.002	379	$\Delta_{0.016} = 287$	(526) (165)
$\text{C}_7\text{H}_7\text{NO}$	Benzamide.....	25	0.016-0.001	(?)	$\Delta_{0.016} = 1.3$	(553)
$\text{C}_7\text{H}_7\text{NO}$	Formanilide.....	0-40 25	0.016 0.10-0.006	380	$5 \times 10^{-10}$	(429) (176)
$\text{C}_7\text{H}_7\text{NO}_2$	<i>o</i> -Aminobenzoic acid.....	25	0.016-0.0005	382	$\Delta_{0.016} = 7.7$	(436, 588, 622)
$\text{C}_7\text{H}_7\text{NO}_2$	<i>m</i> -Aminobenzoic acid.....	0-45 25	0.016-0.0005 0.016-0.001	382	$\Delta_{0.016} = 9.9$	(45, 366, 609) (588, 622)
$\text{C}_7\text{H}_7\text{NO}_2$	<i>p</i> -Aminobenzoic acid.....	0-35 25	0.016-0.0005 0.03-0.0005	382	$\Delta_{0.016} = 8.0$	(45, 436, 611) (436, 588, 622)
$\text{C}_7\text{H}_7\text{NO}_2$	Benzhydroxamic acid.....	0-35 25	0.016-0.0005 0.03-0.015	381	$7.5 \times 10^{-7}$	(45, 609) (426)
$\text{C}_7\text{H}_7\text{NO}_2$	6-Nitroso- <i>m</i> -cresol.....	1-20 25	0.016-0.008 0.008-0.001	380	$3.5 \times 10^{-7}$	(429) (180)
$\text{C}_7\text{H}_7\text{NO}_2$	1-Methylpyrrolglyoxylic acid.....	25	0.03-0.001	382	$2.6 \times 10^{-3}$	(7)
$\text{C}_7\text{H}_7\text{NO}_2$	2-Methylpyrrolketone-5-carboxylic acid.....	25	0.025-0.0008	380	$2.9 \times 10^{-4}$	(7, 378)
$\text{C}_7\text{H}_7\text{NO}_2$	4-Nitrosoorcinol (red isomer).....	25	0.008-0.001	379	$5.0 \times 10^{-4}$	(252)
$\text{C}_7\text{H}_7\text{NO}_2$	4-Nitrosoorcinol (yellow isomer).....	25	0.008-0.0003	379	$4.5 \times 10^{-4}$ $3.6 \times 10^{-4}$ $3.2 \times 10^{-4}$	(180, 522) (252) (261)
$\text{C}_7\text{H}_7\text{NO}_2$	Salicylhydroxamic acid.....	25	0.06-0.008	381	$6.3 \times 10^{-6}$	(426)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	<i>o</i> -Sulfaminebenzoic acid.....	25	0.04-0.0001	380	$2.05 \times 10^{-3}$ $2.25 \times 10^{-3}$	(255) (621); cf. (374)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}(-\text{H}_2\text{O}?)$	Iso- <i>p</i> -sulfaminebenzoic acid.....	25	0.03-0.001	380	$\Delta_{0.03} = 345$	(533)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	<i>p</i> -Sulfaminebenzoic acid.....	25	0.006-0.0008	380	$2.5 \times 10^{-4}$	(255); cf. (374, 533)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	<i>o</i> -Sulfobenzamide.....	0-65 25	0.002-0.0005 0.02-0.00016	380	$\Delta_{0.02} = 338$	(610, 611) (621)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	2-Amino-4-sulfobenzoic acid.....	25	0.007-0.0008	380	$\Delta_{0.0067} = 312.0$	(161)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	3-Amino-4-sulfobenzoic acid.....	25	0.003-0.0008	380	$\Delta_{0.003} = 340.1$	(161)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	4-Amino-2-sulfobenzoic acid.....	25	0.007-0.0008	380	$\Delta_{0.0067} = 187.5$	(161)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	4-Amino-3-sulfobenzoic acid.....	25	0.007-0.0016	380	$\Delta_{0.0067} = 349.1$	(161)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	5-Amino-2-sulfobenzoic acid.....	25	0.007-0.0008	380	$\Delta_{0.0067} = 214.2$	(161)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	5-Amino-3-sulfobenzoic acid.....	25	0.007-0.0008	380	$\Delta_{0.0067} = 165.4$	(161)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$	1, 2, 4- <i>m</i> -Nitrotoluenesulfonic acid.....	25	0.12-0.0005	379	$\Delta_{0.02} = 324$	(610)
$\text{C}_7\text{H}_7\text{NO}_2\text{S}$		0-35	0.12-0.0005			(610)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>7</sub> H <sub>7</sub> NO <sub>3</sub> S	1, 4, 2- <i>m</i> -Nitrotoluenesulfonic acid	25	0.12-0.0005	379	Λ <sub>0.03</sub> = 372	(611)
		0-65	0.12-0.0005			(611)
C <sub>7</sub> H <sub>5</sub> BrNO <sub>3</sub> S	?-Bromo-2-toluidine-?-sulfonic acid	25	0.004-0.0005	378	Λ <sub>0.004</sub> = 169.7	(165)
C <sub>7</sub> H <sub>5</sub> BrNO <sub>3</sub> S	?-Bromo-4-toluidine-2-sulfonic acid	25	0.016-0.0005	378	4.2 × 10 <sup>-3</sup>	(165)
C <sub>7</sub> H <sub>5</sub> BrNO <sub>3</sub> S	3-Bromo-2-toluidine-5-sulfonic acid	25	0.03-0.001	379	Λ <sub>0.03</sub> = 302	(165)
C <sub>7</sub> H <sub>5</sub> INO <sub>3</sub> S	4-Iodo-2-toluidine-5-sulfonic acid	25	0.004-0.0002	379	[Λ <sub>0.004</sub> = 132]	(165)
C <sub>7</sub> H <sub>5</sub> N <sub>2</sub> O <sub>3</sub>	<i>p</i> -Anisole diazonium hydroxide	0	0.008-0.002	137	Λ <sub>0.008</sub> = 116	(166)
C <sub>7</sub> H <sub>5</sub> N <sub>2</sub> O <sub>3</sub>	3, 5-Diaminobenzoic acid	25	0.03-0.0018	379	5 × 10 <sup>-6</sup>	(49)
C <sub>7</sub> H <sub>5</sub> N <sub>2</sub> O <sub>3</sub>	β-Nitrosobenzylhydroxylamine	0	0.002	(?)	5.8 × 10 <sup>-6</sup>	(227)
		25	0.002	(?)	6.5 × 10 <sup>-6</sup>	(227)
C <sub>7</sub> H <sub>5</sub> N <sub>2</sub> O <sub>3</sub> S	2-Nitro-4-toluidine-5-sulfonic acid	25	0.008-0.0002	379	Λ <sub>0.008</sub> = 322	(165)
C <sub>7</sub> H <sub>5</sub> N <sub>2</sub> O <sub>3</sub>	3, 7-Dimethyl-2, 6-dioxypurine	18	0.0016-0.0008	336	Λ <sub>0.0016</sub> = 1.0	(439)
		25	0.0016-0.0008	375	Λ <sub>0.0016</sub> = 1.7	(439)
C <sub>7</sub> H <sub>8</sub> O	<i>o</i> -Cresol	25	0.05-0.03	382	4.2 × 10 <sup>-8</sup>	(26)
C <sub>7</sub> H <sub>8</sub> O	<i>m</i> -Cresol	25	0.05-0.006	382	1.7 × 10 <sup>-8</sup>	(26)
C <sub>7</sub> H <sub>8</sub> O	<i>p</i> -Cresol	25	0.07-0.009	382	1.1 × 10 <sup>-8</sup>	(26)
C <sub>7</sub> H <sub>8</sub> O <sub>2</sub>	2, 6-Dimethylpyrone	25	0.03-0.002	233	6 × 10 <sup>-9</sup>	(572)
C <sub>7</sub> H <sub>8</sub> O <sub>2</sub>	Guaiacol	25	0.04-0.005	383	Λ <sub>0.04</sub> = 0.4	(26)
C <sub>7</sub> H <sub>8</sub> O <sub>2</sub>	Orcinol	25	0.04-0.005	382	Λ <sub>0.01</sub> = 0.5	(26)
C <sub>7</sub> H <sub>8</sub> O <sub>2</sub> S	<i>o</i> -Toluenesulfonic acid	25	0.03-0.001	379	Λ <sub>0.03</sub> = 210	(15)
C <sub>7</sub> H <sub>8</sub> O <sub>2</sub> S	<i>p</i> -Toluenesulfonic acid	18	0.03-0.001	339	Λ <sub>0.03</sub> = 181	(15)
		25	0.03-0.001	379	Λ <sub>0.03</sub> = 213	(15)
		30	0.03-0.001	407	Λ <sub>0.03</sub> = 223	(15)
C <sub>7</sub> H <sub>8</sub> O <sub>3</sub>	2, 4-Dimethylfurfurane-3-carboxylic acid	25	0.002-0.001	381	1.09 × 10 <sup>-5</sup>	(183)
C <sub>7</sub> H <sub>8</sub> O <sub>3</sub> S	<i>o</i> -Anisolesulfonic acid	25	0.03-0.001	379	Λ <sub>0.03</sub> = 208	(15)
C <sub>7</sub> H <sub>8</sub> O <sub>3</sub> S	Benzylsulfonic acid	25	0.12-0.001	379	Λ <sub>0.03</sub> = 363	(143)
C <sub>7</sub> H <sub>8</sub> O <sub>3</sub> S	<i>p</i> -Toluenesulfonic acid	25	0.20-0.0005	380	Λ <sub>0.03</sub> = 358	(143, 145, 312, 603)
		0-65	0.03-0.0005			(145, 610, 611)
C <sub>7</sub> H <sub>8</sub> O <sub>4</sub>	Piperylenedicarboxylic acid	25	0.03-0.001	380	1.14 × 10 <sup>-4</sup>	(514)
C <sub>7</sub> H <sub>8</sub> O <sub>4</sub>	β, γ-Dicarboxy-γ-valerolactone	25	0.03-0.008	377	6 × 10 <sup>-3</sup>	(578)
C <sub>7</sub> H <sub>8</sub> BrN <sub>2</sub> O <sub>3</sub> S	Bromo-2, 6-toluylenediamine-4-sulfonic acid	25	0.007-0.001	379	1.69 × 10 <sup>-4</sup>	(436)
C <sub>7</sub> H <sub>9</sub> N	Benzylamine	25	0.12-0.004	232	2.0 × 10 <sup>-5</sup>	(104)
		0-55	0.06			(251)
C <sub>7</sub> H <sub>9</sub> N	2, 6-Dimethylpyridine	25	0.03-0.004	232	1.0 × 10 <sup>-7</sup>	(414)
C <sub>7</sub> H <sub>9</sub> NO <sub>2</sub>	2, 4-Dimethylpyrrole-3-carboxylic acid	25	0.004-0.001	381	7.4 × 10 <sup>-7</sup>	(7)
C <sub>7</sub> H <sub>9</sub> NO <sub>2</sub>	2, 4-Dimethylpyrrole-5-carboxylic acid	25	0.0013-0.0006	381	2 × 10 <sup>-6</sup>	(7)
C <sub>7</sub> H <sub>9</sub> NO <sub>2</sub>	2, 5-Dimethylpyrrole-3-carboxylic acid	25	0.003-0.0008	381	1.1 × 10 <sup>-6</sup>	(7)
C <sub>7</sub> H <sub>9</sub> NO <sub>2</sub>	Ethyl cyanoacetate	25	0.016-0.001	379	6.2 × 10 <sup>-4</sup>	(213)
C <sub>7</sub> H <sub>9</sub> NO <sub>2</sub>	Methyl cyanopropionylacetate	25	0.004-0.001	378	7.0 × 10 <sup>-4</sup>	(214)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S	<i>p</i> -Aminobenzylsulfonic acid	25	0.008-0.001	379	2.29 × 10 <sup>-6</sup>	(165)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S	1-Methylaniline-4-sulfonic acid	25	0.008-0.0005	377	6.52 × 10 <sup>-4</sup>	(165)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S	2-Toluidine-4-sulfonic acid	25	0.03-0.001	379	2.4 × 10 <sup>-4</sup>	(102, 165, 436)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S	2-Toluidine-5-sulfonic acid	25	0.03-0.001	379	7.36 × 10 <sup>-4</sup>	(102, 165, 436)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S	3-Toluidine-2-sulfonic acid	25	0.008-0.001	379	3.50 × 10 <sup>-4</sup>	(165, 436)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S	4-Toluidine-?-sulfonic acid	25	0.016-0.001	380	7.6 × 10 <sup>-4</sup>	(436)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S	4-Toluidine-2,5-nic acid	25	0.03-0.005	379	4.00 × 10 <sup>-6</sup>	(102, 165)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S	4-Toluidine-3-sulfonic acid	25	0.03-0.001	379	8.33 × 10 <sup>-4</sup>	(102, 165)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S <sub>2</sub>	2-Toluidine-3, 5-disulfonic acid	25	0.016-0.0005	380	Λ <sub>0.016</sub> = 354	(165)
C <sub>7</sub> H <sub>9</sub> NO <sub>3</sub> S <sub>2</sub>	3-Toluidine-2, 4-disulfonic acid	25	0.03-0.0005	380	Λ <sub>0.016</sub> = 90.2	(165)
C <sub>7</sub> H <sub>9</sub> N <sub>2</sub> O <sub>3</sub> S	2-Nitro-4-tolylhydrazine-5-sulfonic acid	25	0.002-0.0002	376	1 × 10 <sup>-4</sup>	(165)
C <sub>7</sub> H <sub>10</sub> AsNO <sub>3</sub>	<i>o</i> -Toluidinearsonic acid	25	0.016-0.001	372	5.3 × 10 <sup>-5</sup>	(356)
C <sub>7</sub> H <sub>10</sub> AsNO <sub>3</sub>	<i>m</i> -Toluidinearsonic acid	25	0.008-0.001	372	1.3 × 10 <sup>-4</sup>	(355)
C <sub>7</sub> H <sub>10</sub> Br <sub>2</sub> O <sub>3</sub>	Dibromohydroshikimic acid	12	0.02-0.003	314	7.5 × 10 <sup>-5</sup>	(177)
C <sub>7</sub> H <sub>10</sub> N <sub>2</sub> O <sub>3</sub> S	2, 4-Toluylenediamine-5-sulfonic acid	25	0.004-0.00025	376	2.10 × 10 <sup>-4</sup>	(165)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Delta_0$	<i>k</i> (or $\Delta_c$ )	Lit.
Formula	Name					
C <sub>7</sub> H <sub>10</sub> N <sub>2</sub> O <sub>2</sub> S	2, 6-Toluylenediamine-4-sulfonic acid.....	25	0.016-0.001	379	$4.6 \times 10^{-5}$	(436)
C <sub>7</sub> H <sub>10</sub> O <sub>2</sub>	<i>m</i> -Methyldihydroresorcinol.....	25	0.06-0.001	379	$5.6 \times 10^{-6}$	(508)
C <sub>7</sub> H <sub>10</sub> O <sub>2</sub>	$\Delta^1$ -Tetrahydrobenzoic acid:					
	(a) Liquid phase.....	25	0.03-0.001	380	$2.10 \times 10^{-5}$	(13)
	(b) Solid phase.....	25	0.03-0.001	380	$2.18 \times 10^{-5}$	(13)
C <sub>7</sub> H <sub>10</sub> O <sub>2</sub>	$\Delta^2$ -Tetrahydrobenzoic acid.....	25	0.06-0.001	380	$3.0 \times 10^{-5}$	(13)
C <sub>7</sub> H <sub>10</sub> O <sub>3</sub>	Hexic acid.....	25	0.016-0.004	378	$8.3 \times 10^{-5}$	(569)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Allylsuccinic acid.....	25	0.03-0.001	379	$1.07 \times 10^{-4}$	(577)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	1, 2-Dimethylcyclopropane-1, 2-dicarboxylic acid.....	25	0.04-0.005	380	$9.90 \times 10^{-5}$	(264)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	$\alpha$ , $\alpha'$ -Dimethylglutaconic acid.....	25	0.03-0.001	378	$1.27 \times 10^{-4}$	(550)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	$\alpha$ -Ethylideneglutaric acid.....	25	0.03-0.001	380	$3.2 \times 10^{-5}$	(408)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Ethylitaconic acid.....	25	0.06-0.001	378	$3.5 \times 10^{-5}$	(191)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Ethyl hydroxymethyleneacetoacetate.....	3.7	0.016-0.002	262	$2.3 \times 10^{-5}$	(124)
		23.5	0.04-0.002	368	$2.9 \times 10^{-5}$	(124)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Hydroxypimelic acid anhydride.....	25	0.03-0.001	378	$2.72 \times 10^{-5}$	(615)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	$\alpha$ -Monoethyl mesaconate.....	25	0.03-0.001	380	$3.38 \times 10^{-4}$	(9)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	$\beta$ -Monoethyl mesaconate.....	25	0.03-0.001	379	$5.5 \times 10^{-4}$	(9)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Methylenedimethylsuccinic acid.....	25	0.10-0.012	378	$1.64 \times 10^{-4}$	(92)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Methylethylmaleic acid.....	25	0.03-0.001	379	$9.4 \times 10^{-5}$	(334, 577)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	<i>cis</i> -Pentamethylene-1, 2-dicarboxylic acid.....	25	(?)	378	$1.58 \times 10^{-4}$	(447)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	<i>trans</i> -Pentamethylene-1, 2-dicarboxylic acid.....	25	0.016-0.0009	378	$1.16 \times 10^{-4}$	(524, 582)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	<i>cis</i> -Pentamethylene-1, 3-dicarboxylic acid.....	25	0.06-0.001	378	$5.2 \times 10^{-5}$	(460)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	<i>trans</i> -Pentamethylene-1, 3-dicarboxylic acid.....	25	0.06-0.001	378	$4.9 \times 10^{-5}$	(460)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Propenylsuccinic acid.....	25	0.06-0.001	378	$5.8 \times 10^{-5}$	(191)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Propylfumaric acid.....	25	0.016-0.001	379	$9.1 \times 10^{-4}$	(577)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Teraconic acid.....	25	0.02-0.0013	378	$1.38 \times 10^{-4}$	(524)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Terebic acid.....	25	0.03-0.001	378	$2.6 \times 10^{-4}$	(436)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	Dimethyl acetylmalonate.....	25	0.008	(?)	[ $\Delta_{0.008} = 12$ ]	(213)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	Dimethyldihydroxyglutaric lactone.....	25	0.02-0.0007	379	$5 \times 10^{-5}$	(631)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	Hydrochelidonic acid.....	25	0.06-0.002	378	$4.5 \times 10^{-5}$	(378)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	Shikimic acid.....	14.1	0.01-0.0002	323	$7.1 \times 10^{-5}$	(177)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	Acetyl- $\beta$ -hydroxyglutaric acid.....	25	0.02-0.003	377	$1.54 \times 10^{-4}$	(84)
		0	0.02-0.003			(84)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	Butenyltricarboxylic acid.....	25	0.03-0.001	378	$3.26 \times 10^{-5}$	(578)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	Isobutenyltricarboxylic acid.....	25	0.03-0.001	378	$3.26 \times 10^{-5}$	(578)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	$\beta$ -Dimethylethenyltricarboxylic acid.....	25	0.03-0.002	377	$4.9 \times 10^{-5}$	(578)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	<i>fum.</i> - $\alpha$ -Methyltricarballic acid.....	25	0.05-0.001	376	$3.15 \times 10^{-4}$	(98, 578)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	<i>mal.</i> - $\alpha$ -Methyltricarballic acid.....	25	0.05-0.006	375	$4.75 \times 10^{-4}$	(98)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	$\alpha$ -Monomethyl tricarballylate.....	25	0.14-0.016	375	$7.5 \times 10^{-5}$	(98)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub>	$\beta$ -Monomethyl tricarballylate.....	25	0.09-0.001	375	$9.3 \times 10^{-5}$	(98)
C <sub>7</sub> H <sub>10</sub> O <sub>6</sub> S <sub>2</sub>	Methinetriethioglycolic acid.....	25	0.03-0.002	378	$9.1 \times 10^{-4}$	(281)
C <sub>7</sub> H <sub>11</sub> NO <sub>2</sub>	<i>dl</i> -Ecgonic acid.....	25	0.03-0.0015	376	$8.3 \times 10^{-5}$	(617)
C <sub>7</sub> H <sub>11</sub> NO <sub>4</sub>	<i>N</i> -Methylpyrrolidine- $\alpha$ , $\alpha'$ -dicarboxylic acid.....	25	0.06-0.001	(?)	$\Delta_{0.06} = 136$	(618)
C <sub>7</sub> H <sub>11</sub> NO <sub>4</sub>	Diethyl nitromalonate.....	25	0.012-0.006	378	$7.2 \times 10^{-4}$	(233)
C <sub>7</sub> H <sub>12</sub> O <sub>2</sub>	$\alpha$ -Ethyl- $\alpha$ , $\beta$ -pentenic acid.....	25	0.016-0.001	378	$2.1 \times 10^{-5}$	(189)
C <sub>7</sub> H <sub>12</sub> O <sub>2</sub>	$\alpha$ -Ethyl- $\beta$ , $\gamma$ -pentenic acid.....	25	0.03-0.001	378	$3.5 \times 10^{-5}$	(189)
C <sub>7</sub> H <sub>12</sub> O <sub>2</sub>	$\alpha$ , $\beta$ -Heptenic acid.....	25	0.016-0.001	379	$1.5 \times 10^{-5}$	(494)
C <sub>7</sub> H <sub>12</sub> O <sub>2</sub>	Hexahydrobenzoic acid.....	25	0.016-0.0008	378	$1.28 \times 10^{-5}$	(361, 525.2, 635)
C <sub>7</sub> H <sub>12</sub> O <sub>2</sub>	1-Methylpentamethylene-2-carboxylic acid.....	25	0.02-0.001	378	$1.05 \times 10^{-5}$	(635)
C <sub>7</sub> H <sub>12</sub> O <sub>2</sub>	$\delta$ -Acetovaleric acid.....	25	0.02-0.001	378	$1.90 \times 10^{-5}$	(150)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>7</sub> H <sub>12</sub> O <sub>3</sub>	α-Dimethyllevulinic acid.....	25	(?)	(?)	1.08 × 10 <sup>-5</sup>	(61)
C <sub>7</sub> H <sub>12</sub> O <sub>3</sub>	α-Ethyl-β-acetylpropionic acid....	25	(?)	(?)	2.93 × 10 <sup>-6</sup>	(61)
C <sub>7</sub> H <sub>12</sub> O <sub>3</sub>	β-Methyl-γ-acetylbutyric acid....	25	0.06-0.001	377	2.65 × 10 <sup>-6</sup>	(508)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Butylmalonic acid.....	25	0.03-0.002	380	1.01 × 10 <sup>-3</sup>	(390, 577)
		0-65	0.03-0.0005			(526)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Isobutylmalonic acid.....	25	0.03-0.001	380	8.82 × 10 <sup>-4</sup>	(390, 577)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Diethylmalonic acid.....	25	0.03-0.004	380	7.1 × 10 <sup>-3</sup>	(390, 577)
		0-65	1.0-0.0005			(68, 526)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	β, β-Dimethylglutaric acid.....	25	0.03-0.001	377	2.2 × 10 <sup>-4</sup>	(451)
					2.0 × 10 <sup>-4</sup>	(20, 525.2)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	fum.-sym.-Dimethylglutaric acid...	25	0.03-0.0006	377	5.7 × 10 <sup>-5</sup>	(19, 470, 550); cf. (49, 577)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	mal.-sym.-Dimethylglutaric acid...	25	0.03-0.0009	377	5.3 × 10 <sup>-5</sup>	(19, 49, 94, 470, 550, 577, 631)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Monoethyl dimethylmalonate.....	25	0.02-0.0007	376	3.04 × 10 <sup>-4</sup>	(582)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	α-Monomethyl asym.-dimethylsuc- cinate.....	25	0.05-0.005	376	2.28 × 10 <sup>-5</sup>	(100)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	β-Monomethyl asym.-dimethylsuc- cinate.....	25	0.09-0.005	376	2.6 × 10 <sup>-5</sup>	(100)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Monomethyl sym.-anti-dimethyl- succinate.....	25	0.05-0.006	376	4.5 × 10 <sup>-5</sup>	(100)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Monomethyl sym.-p-dimethylsuc- cinate.....	25	0.03-0.004	376	6.0 × 10 <sup>-5</sup>	(100)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	α-Ethylglutaric acid.....	25	0.02-0.0005	377	5.5 × 10 <sup>-5</sup>	(391)
					5.8 × 10 <sup>-5</sup>	(20, 451)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	β-Ethylglutaric acid.....	25	0.03-0.001	(?)	5.3 × 10 <sup>-5</sup>	(525.5)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Monoethyl ethylmalonate.....	25	0.03-0.001	376	4.01 × 10 <sup>-4</sup>	(582)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Diethyl malonate.....	25	0.04-0.01	379	1.2 × 10 <sup>-3</sup>	(568, 573); cf. (275)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	α-Methyladipic acid.....	24.4	0.02-0.001	376	4.0 × 10 <sup>-4</sup>	(391)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	fum.-sym.-Methylethylsuccinic acid.....	25	0.03-0.001	378	2.05 × 10 <sup>-4</sup>	(20, 21, 49, 451, 577)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	mal.-sym.-Methylethylsuccinic acid	25	0.03-0.001	378	2.00 × 10 <sup>-4</sup>	(21, 49, 451, 577)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Methylpropylmalonic acid.....	25	0.06-0.001	377	1.82 × 10 <sup>-3</sup>	(390)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Methylisopropylmalonic acid.....	25	0.03-0.001	377	1.2 × 10 <sup>-3</sup>	(390)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	n-Pimelic acid.....	25	0.03-0.001	377	3.20 × 10 <sup>-5</sup>	(524, 565)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	γ-Pimelic acid.....	25	0.03-0.001	377	4.12 × 10 <sup>-5</sup>	(577, 582, 631)
					3.92 × 10 <sup>-5</sup>	(436)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Isopimelic acid.....	25	0.03-0.001	377	9.5 × 10 <sup>-6</sup>	(577)
					3.40 × 10 <sup>-6</sup>	(385)
					3.50 × 10 <sup>-6</sup>	(21, 58, 577)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Propylsuccinic acid.....	25	0.03-0.002	377	8.7 × 10 <sup>-6</sup>	(569, 577)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Isopropylsuccinic acid.....	25	0.016-0.001	377	7.4 × 10 <sup>-6</sup>	(569, 577)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Trimethylsuccinic acid.....	25	0.03-0.001	377	3.1 × 10 <sup>-4</sup>	(25, 95, 561, 577, 631, 632)
C <sub>7</sub> H <sub>12</sub> O <sub>5</sub>	α, α'-Dimethyl-β-hydroxyglutaric acid.....	25	0.014-0.0008	376	1.06 × 10 <sup>-4</sup>	(471, 550)
C <sub>7</sub> H <sub>12</sub> O <sub>5</sub>	Hydroshikimic acid.....	19	0.3-0.02	348	3.0 × 10 <sup>-5</sup>	(177)
C <sub>7</sub> H <sub>12</sub> O <sub>5</sub>	Hydroxytrimethylsuccinic acid....	25	0.07-0.0004	378	9.2 × 10 <sup>-4</sup>	(92)
					8.3 × 10 <sup>-4</sup>	(22)
C <sub>7</sub> H <sub>12</sub> O <sub>5</sub>	Dimethyldihydroxyglutaric acid...	25	0.03-0.0009	379	1.7 × 10 <sup>-3</sup>	(631)
C <sub>7</sub> H <sub>12</sub> O <sub>5</sub>	dl-Quinic acid.....	9	0.15-0.005	303	2.2 × 10 <sup>-4</sup>	(177)
C <sub>7</sub> H <sub>12</sub> O <sub>5</sub>	Quinic acid.....	14.1	0.13-0.0005	314	2.9 × 10 <sup>-4</sup>	(177)
		25	0.03-0.002	376	2.8 × 10 <sup>-4</sup>	(378, 527)
C <sub>7</sub> H <sub>14</sub> O <sub>7</sub>	Dihydroxyhydroshikimic acid.....	19	0.05-0.003	347	7.1 × 10 <sup>-4</sup>	(177)
C <sub>7</sub> H <sub>14</sub> O <sub>2</sub>	Heptic acid.....	25	0.01-0.001	378	1.30 × 10 <sup>-5</sup>	(200); cf. (163)
C <sub>7</sub> H <sub>14</sub> O <sub>3</sub>	β-Diethylethylenelactic acid.....	25	0.03-0.0009	376	2.97 × 10 <sup>-5</sup>	(550)
C <sub>7</sub> H <sub>14</sub> O <sub>3</sub>	Dimethylethylenelactic acid..	25	0.03-0.001	376	1.48 × 10 <sup>-5</sup>	(550)
C <sub>7</sub> H <sub>14</sub> O <sub>3</sub>	Tetramethylethylenelactic acid....	25	0.03-0.001	376	4.27 × 10 <sup>-5</sup>	(550)
C <sub>7</sub> H <sub>14</sub> O <sub>6</sub>	α-Methylglucoside.....	25	0.5	(?)	Λ <sub>0.1</sub> = 0.05	(71)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Delta_0$	<i>k</i> (or $\Delta_c$ )	Lit.
Formula	Name					
C <sub>7</sub> H <sub>14</sub> O <sub>6</sub>	$\beta$ -Methylglucoside.....	25	0.5	(?)	$\Delta_{0.5} = 0.05$	(71)
C <sub>8</sub> H <sub>2</sub> Cl <sub>4</sub> O <sub>4</sub>	Tetrachlorophthalic acid.....	25	0.002-0.0005	[378]	$\Delta_{0.002} = 470$	(610)
		0-65	0.002-0.0005			(610, 611)
C <sub>8</sub> H <sub>4</sub> Cl <sub>2</sub> O <sub>4</sub>	3, 6-Dichlorophthalic acid.....	25	0.03-0.001	379	$3.4 \times 10^{-3}$	(598)
C <sub>8</sub> H <sub>4</sub> Cl <sub>2</sub> O <sub>4</sub>	4, 5-Dichlorophthalic acid.....	25	0.008-0.0005	379	$\Delta_{0.008} = 306$	(610)
		0-65	0.008-0.0005			(610, 614)
C <sub>8</sub> H <sub>6</sub> BrO <sub>4</sub>	2-Bromoterephthalic acid.....	25	0.006-0.001	379	$6 \times 10^{-3}$	(598)
C <sub>8</sub> H <sub>6</sub> ClO <sub>4</sub>	4-Chlorophthalic acid.....	25	0.016-0.004	380	$\Delta_{0.016} = 276$	(436)
C <sub>8</sub> H <sub>6</sub> NO <sub>2</sub>	<i>m</i> -Cyanobenzoic acid.....	25	0.008-0.001	380	$1.95 \times 10^{-4}$	(436)
C <sub>8</sub> H <sub>6</sub> NO <sub>2</sub>	Phthalimide.....	25	0.0022-0.0018	378	$[4 \times 10^{-8}]$	(362); cf. (624)
C <sub>8</sub> H <sub>6</sub> NO <sub>5</sub>	2-Aldehyde-3-nitrobenzoic acid....	25	0.008-0.001	380	$1.30 \times 10^{-8}$	(540)
C <sub>8</sub> H <sub>6</sub> NO <sub>5</sub>	2-Aldehyde-5-nitrobenzoic acid....	25	0.008-0.001	380	$9.8 \times 10^{-8}$	(540)
C <sub>8</sub> H <sub>6</sub> NO <sub>5</sub> S	Sulfimidophthalic acid.....	25	0.01-0.005	(?)	$\Delta_{0.01} = 338$	(637)
C <sub>8</sub> H <sub>6</sub> NO <sub>6</sub>	3-Nitrophthalic acid.....	25	0.06-0.001	378	$1.25 \times 10^{-3}$	(436, 598)
C <sub>8</sub> H <sub>6</sub> NO <sub>6</sub>	2-Nitrotterephthalic acid.....	25	0.05-0.002	378	$1.9 \times 10^{-3}$	(598)
C <sub>8</sub> H <sub>6</sub> NO <sub>6</sub>	4-Nitrophthalic acid.....	25	0.03-0.001	378	$7.5 \times 10^{-3}$	(436, 598)
C <sub>8</sub> H <sub>6</sub> NO <sub>6</sub>	4-Nitroisophthalic acid.....	25	0.03-0.001	378	$\Delta_{0.03} = 166.7$	(601)
C <sub>8</sub> H <sub>6</sub> NO <sub>6</sub>	Pyridine-2, 3, 4-tricarboxylic acid..	25	0.016-0.0002	(?)	$\Delta_{0.008} = 307$	(436)
C <sub>8</sub> H <sub>6</sub> NO <sub>6</sub>	Pyridine-2, 3, 5-tricarboxylic acid..	25	0.008-0.0002	(?)	$\Delta_{0.008} = 295$	(436)
C <sub>8</sub> H <sub>6</sub> NO <sub>6</sub>	Pyridine-3, 4, 5-tricarboxylic acid..	25	0.008-0.0002	(?)	$\Delta_{0.008} = 248$	(436)
C <sub>8</sub> H <sub>6</sub> N <sub>5</sub> O <sub>6</sub>	Purpuric acid.....	0	0.002	240	$2 \times 10^{-3}$	(248)
C <sub>8</sub> H <sub>6</sub> BrClO <sub>6</sub>	Methyl 2-chloro-6-bromogallate....	25	0.03-0.004	374	$4 \times 10^{-6}$	(135)
C <sub>8</sub> H <sub>6</sub> BrN <sub>3</sub> O	<i>p</i> -Bromophenyleyanourea.....	25	0.0005	380	$2.4 \times 10^{-4}$	(64)
C <sub>8</sub> H <sub>6</sub> Br <sub>2</sub> O <sub>6</sub>	Methyl dibromogallate.....	25	0.03-0.004	375	$1.1 \times 10^{-6}$	(135)
C <sub>8</sub> H <sub>6</sub> ClNO <sub>2</sub>	<i>o</i> -Chlorooxanilic acid.....	25	0.03-0.001	377	$1.95 \times 10^{-3}$	(436)
C <sub>8</sub> H <sub>6</sub> ClNO <sub>2</sub>	<i>p</i> -Chlorooxanilic acid.....	25	0.004-0.001	377	$1.30 \times 10^{-3}$	(436)
C <sub>8</sub> H <sub>6</sub> Cl <sub>2</sub> O <sub>3</sub>	2-Methoxy-3, 5-dichlorobenzoic acid.....	25	0.0005-0.0002	379	$1.3 \times 10^{-3}$	(135)
C <sub>8</sub> H <sub>6</sub> Cl <sub>2</sub> O <sub>4</sub>	Methyl 3, 4-dihydroxy-2, 5-dichlorobenzoate.....	25	0.004-0.001	377	$4.4 \times 10^{-8}$	(135)
C <sub>8</sub> H <sub>6</sub> Cl <sub>2</sub> O <sub>6</sub>	Methyl 2, 6-dichlorogallate.....	25	0.03-0.004	375	$5.8 \times 10^{-7}$	(135)
C <sub>8</sub> H <sub>6</sub> N <sub>3</sub> O	<i>N</i> -Cyanobenzamide.....	25	0.03-0.0007	380	$2.0 \times 10^{-3}$	(237)
					$1.8 \times 10^{-3}$	(26)
C <sub>8</sub> H <sub>6</sub> N <sub>2</sub> O <sub>2</sub>	Dihydroxyquinazoline.....	25	0.002	(?)	$\Delta_{0.002} = 2.9$	(85)
C <sub>8</sub> H <sub>6</sub> N <sub>2</sub> O <sub>2</sub>	Isatoxime.....	25	0.002-0.001	377	$[2 \times 10^{-10}]$	(235)
C <sub>8</sub> H <sub>6</sub> N <sub>4</sub> O <sub>3</sub>	Alloxanthine.....	25	0.008-0.001	375	$\Delta_{0.004} = 46.4$	(85, 557)
C <sub>8</sub> H <sub>6</sub> O <sub>3</sub>	Benzoylformic acid.....	25	0.07-0.008	378	$4.8 \times 10^{-3}$	(69)
C <sub>8</sub> H <sub>6</sub> O <sub>3</sub>	Phenylglyoxylic acid.....	25	0.03-0.001	379	$6 \times 10^{-3}$	(26)
C <sub>8</sub> H <sub>6</sub> O <sub>3</sub>	Phthalaldehydic acid.....	25	0.02-0.0013	380	$3.10 \times 10^{-3}$	(601)
C <sub>8</sub> H <sub>6</sub> O <sub>4</sub>	Phthalic acid.....	25	0.06-0.0008	380	$1.17 \times 10^{-3}$	(330, 436, 476)
		0-65	0.03-0.0005			(45, 126, 328, 526, 609)
C <sub>8</sub> H <sub>6</sub> O <sub>4</sub>	Isophthalic acid.....	25	0.002-0.001	380	$2.80 \times 10^{-4}$	(436)
		0	0.002-0.0004			(328)
C <sub>8</sub> H <sub>6</sub> O <sub>4</sub> S	Thienylpyrrolacemic acid.....	25	0.004-0.001	380	$4.5 \times 10^{-3}$	(7)
C <sub>8</sub> H <sub>6</sub> O <sub>6</sub>	2-Hydroxyterephthalic acid.....	25	0.005-0.0012	379	$2.65 \times 10^{-3}$	(436, 598)
C <sub>8</sub> H <sub>6</sub> O <sub>6</sub>	4-Hydroxyphthalic acid.....	25	0.06-0.001	378	$1.20 \times 10^{-3}$	(598)
C <sub>8</sub> H <sub>7</sub> BrO <sub>2</sub>	Phenylbromoacetic acid.....	25	0.01-0.0005	380	$3.5 \times 10^{-3}$	(515)
C <sub>8</sub> H <sub>7</sub> ClO <sub>2</sub>	Phenylchloroacetic acid.....	25	0.02-0.0005	380	$4.3 \times 10^{-3}$	(513, 515)
C <sub>8</sub> H <sub>7</sub> ClO <sub>3</sub>	3-Methoxy-6-chlorobenzoic acid....	25	0.002-0.0005	379	$1.3 \times 10^{-3}$	(135)
C <sub>8</sub> H <sub>7</sub> ClO <sub>6</sub>	Methyl 2-chlorogallate.....	25	0.03-0.004	376	$2.5 \times 10^{-7}$	(135)
C <sub>8</sub> H <sub>7</sub> NO <sub>3</sub>	1 <sup>2</sup> -Nitroacetophenone.....	25	0.004-0.001	376	$6.1 \times 10^{-6}$	(254)
C <sub>8</sub> H <sub>7</sub> NO <sub>3</sub>	Oxanilic acid.....	25	0.03-0.002	377	$1.17 \times 10^{-3}$	(422, 436)
C <sub>8</sub> H <sub>7</sub> NO <sub>3</sub>	Phenylglyoxylic acid <i>anti</i> -oxime...	25	0.06-0.015	380	$1.5 \times 10^{-3}$	(244)
C <sub>8</sub> H <sub>7</sub> NO <sub>3</sub>	Phenylglyoxylic acid <i>syn</i> -oxime...	25	0.06-0.001	380	$1.75 \times 10^{-3}$	(26, 265)
					$1.52 \times 10^{-3}$	(244, 265)
C <sub>8</sub> H <sub>7</sub> NO <sub>3</sub>	<i>o</i> -Phthalamic acid.....	25	0.03-0.001	379	$1.57 \times 10^{-4}$	(436)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	2-Aminoterephthalic acid.....	25	0.002-0.001	379	$2.6 \times 10^{-4}$	(540)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	3-Methyl-4-nitrobenzoic acid.....	25	0.001-0.0005	379	$3.1 \times 10^{-4}$	(601)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	2-Methylpyridine-3, 5-dicarboxylic acid.....	25	0.008-0.001	379	$1.95 \times 10^{-3}$	(436)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	α-Monomethyl pyridine-2, 3-dicarboxylate.....	25	0.016-0.0005	379	2.60 × 10 <sup>-3</sup>	(319)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	β-Monomethyl pyridine-2, 3-dicarboxylate.....	25	0.016-0.0005	379	1.38 × 10 <sup>-3</sup>	(319)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	β-Monomethyl pyridine-3, 4-dicarboxylate.....	25	0.016-0.0005	379	6.52 × 10 <sup>-4</sup>	(319)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	γ-Monomethyl pyridine-3, 4-dicarboxylate.....	25	0.016-0.0005	379	6.5 × 10 <sup>-4</sup>	(319)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	2-Pyrrolylpyrrolacemic acid.....	25	0.005-0.0006	380	8.8 × 10 <sup>-4</sup>	(7)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	o-Nitrophenoxyacetic acid.....	25	0.016-0.001	378	1.55 × 10 <sup>-3</sup>	(436)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	p-Nitrophenoxyacetic acid.....	25	0.008-0.001	378	1.50 × 10 <sup>-3</sup>	(436)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	4-Nitro-2-hydroxy-5-methoxybenzoic acid.....	15	0.004-0.001	319	8.5 × 10 <sup>-3</sup>	(323)
		25	0.008-0.001	378	1.0 × 10 <sup>-2</sup>	(323)
		35	0.004-0.001	432	1.0 × 10 <sup>-2</sup>	(323)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	5-Nitro-2-hydroxy-3-methoxybenzoic acid.....	15	0.004-0.001	319	8.0 × 10 <sup>-3</sup>	(323)
		25	0.004-0.001	378	9.0 × 10 <sup>-3</sup>	(323)
		35	0.004-0.001	432	9.5 × 10 <sup>-3</sup>	(323)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	5-Nitro-3-hydroxy-4-methoxybenzoic acid.....	15	0.004-0.001	319	2.65 × 10 <sup>-4</sup>	(323)
		25	0.004-0.001	378	2.70 × 10 <sup>-4</sup>	(323)
		35	0.004-0.001	432	2.75 × 10 <sup>-4</sup>	(323)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	5-Nitro-4-hydroxy-3-methoxybenzoic acid.....	15	0.004-0.001	319	1.65 × 10 <sup>-4</sup>	(323)
		25	0.004-0.001	378	1.70 × 10 <sup>-4</sup>	(323)
		35	0.004-0.001	432	1.50 × 10 <sup>-4</sup>	(323)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub>	Nitrovanillic acid.....	25	0.016-0.004	378	1.15 × 10 <sup>-4</sup>	(49)
C <sub>8</sub> H <sub>7</sub> NO <sub>4</sub> S	Sulfaminephthalic acid.....	25	0.01-0.005	(?)	Λ <sub>0.01</sub> = 209	(637)
C <sub>8</sub> H <sub>7</sub> N <sub>3</sub>	C-Phenylosotriazole.....	20	0.004	(?)	Λ <sub>0.004</sub> = 3.96	(429)
		0.5-40	0.004			(429)
C <sub>8</sub> H <sub>7</sub> N <sub>3</sub> OS	1-Phenyl-3-thiourazole.....	25	0.016-0.004	379	1.7 × 10 <sup>-2</sup>	(6)
C <sub>8</sub> H <sub>7</sub> N <sub>3</sub> O <sub>2</sub>	1-Phenylurazole.....	25	0.002-0.0001	380	1.1 × 10 <sup>-5</sup>	(6)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	2-Hydroxy-m-toluic aldehyde.....	25	0.008-0.001	380	1.49 × 10 <sup>-6</sup>	(204)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	4-Hydroxy-m-toluic aldehyde.....	25	0.008-0.0005	380	2.13 × 10 <sup>-6</sup>	(204)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	6-Hydroxy-m-toluic aldehyde.....	25	0.008-0.001	380	4.57 × 10 <sup>-6</sup>	(204)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	5-Hydroxy-o-toluic aldehyde.....	25	0.008-0.001	380	2.86 × 10 <sup>-6</sup>	(204)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	3-Hydroxy-p-toluic aldehyde.....	25	0.004-0.0005	380	7.5 × 10 <sup>-6</sup>	(204)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	Phenylacetic acid.....	25	0.03-0.001	381	5.45 × 10 <sup>-6</sup>	(436); cf. (537)
		0-65	0.03-0.0005			(526, 608, 609)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	α-Isophenylacetic acid.....	25	0.013-0.0011	381	3.70 × 10 <sup>-6</sup>	(486)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	β-Isophenylacetic acid (γ-cycloheptatrienecarboxylic acid).....	25	0.016-0.001	381	4.02 × 10 <sup>-6</sup>	(486)
					3.74 × 10 <sup>-6</sup>	(616)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	δ-Isophenylacetic acid.....	25	0.016-0.001	381	3.88 × 10 <sup>-6</sup>	(616)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	o-Toluic acid.....	0	0.003-0.001	243	1.34 × 10 <sup>-4</sup>	(172)
		20	0.003-0.001	353	1.20 × 10 <sup>-4</sup>	(172)
		25	0.008-0.001	382	1.17 × 10 <sup>-4</sup>	(172, 436, 451)
		30	0.003-0.001	410	1.10 × 10 <sup>-4</sup>	(172)
		35	0.003-0.001	438	1.05 × 10 <sup>-4</sup>	(172)
		40	0.003-0.001	464	1.00 × 10 <sup>-4</sup>	(172)
		45	0.003-0.001	487	9.6 × 10 <sup>-5</sup>	(172)
		50	0.003-0.001	511	9.2 × 10 <sup>-5</sup>	(172)
		0-99	0.008-0.0005			(506, 525, 609)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	m-Toluic acid.....	25	0.008-0.001	381	5.05 × 10 <sup>-5</sup>	(436, 451)
		0-99	0.002-0.0005			(506, 525, 609)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	p-Toluic acid.....	25	0.004-0.0005	387	5.05 × 10 <sup>-5</sup>	(436)
					4.55 × 10 <sup>-5</sup>	(457)
					3.80 × 10 <sup>-5</sup>	(451)
		0-99	0.002-0.0005			(506, 525, 609)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	pseudo-m-Toluic acid.....	[25]	(?)	(?)	1.3 × 10 <sup>-4</sup>	(449)
C <sub>8</sub> H <sub>7</sub> O <sub>2</sub>	o-Hydroxymethylbenzoic acid.....	25	0.02-0.0003	378	1.45 × 10 <sup>-4</sup>	(128, 269)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Delta$	<i>k</i> (or $\Delta$ )	Lit.
Formula	Name					
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	2-Hydroxy- <i>m</i> -toluic acid.....	25	0.002-0.0005	380	1.00 × 10 <sup>-3</sup>	(378, 457, 536)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	4-Hydroxy- <i>m</i> -toluic acid.....	25	0.004-0.0005	380	8.6 × 10 <sup>-4</sup>	(378, 457, 536)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	3-Hydroxy- <i>o</i> -toluic acid.....	25	0.0009	380	1.04 × 10 <sup>-3</sup>	(536)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	6-Hydroxy- <i>o</i> -toluic acid.....	25	0.004-0.0005	381	1.66 × 10 <sup>-4</sup>	(457)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	3-Hydroxy- <i>p</i> -toluic acid.....	25	0.004-0.0005	380	7.2 × 10 <sup>-4</sup>	(378, 457, 536)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	<i>o</i> -Methoxybenzoic acid.....	25	0.03-0.001	381	8.0 × 10 <sup>-3</sup>	(436)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	<i>m</i> -Methoxybenzoic acid.....	25	0.004-0.0002	381	8.7 × 10 <sup>-3</sup>	(457)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	<i>p</i> -Methoxybenzoic acid.....	25	0.002-0.0005	381	8.8 × 10 <sup>-3</sup>	(457)
					3.1 × 10 <sup>-5</sup>	(436)
					3.6 × 10 <sup>-5</sup>	(457)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	Orcyl aldehyde.....	0-99	0.004-0.0005			(506, 526)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	Phenoxyacetic acid.....	25	0.001-0.0001	380	4.00 × 10 <sup>-5</sup>	(204)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	<i>d</i> -Phenylglycolic acid.....	25	0.03-0.001	380	7.4 × 10 <sup>-4</sup>	(436, 536)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	<i>l</i> -Phenylglycolic acid.....	25	0.5-0.001	379	4.3 × 10 <sup>-4</sup>	(73)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	<i>dl</i> -Phenylglycolic acid.....	25	(?)	(?)	4.2 × 10 <sup>-4</sup>	(570)
			1.0-0.001	379	4.09 × 10 <sup>-4</sup>	(378, 436)
					4.3 × 10 <sup>-4</sup>	(73); cf. (570)
C <sub>8</sub> H <sub>5</sub> O <sub>3</sub>	Vanillin.....	0-65	0.12-0.0005			(525, 609)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	Dehydroacetic acid.....	25	0.008-0.001	380	4.72 × 10 <sup>-6</sup>	(204)
		25	0.01-0.001	379	5.3 × 10 <sup>-6</sup>	(436)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	Isodehydroacetic acid.....	25	0.03-0.001		1 × 10 <sup>-5</sup>	(129)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	$\Delta^{1,3}$ -Dihydrophthalic acid.....	25	0.03-0.0001	378	5.3 × 10 <sup>-3</sup>	(378, 436)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	$\Delta^{2,4}$ -Dihydrophthalic acid.....	25	(?)	380	7 × 10 <sup>-4</sup>	(1)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	$\Delta^{2,5}$ -Dihydrophthalic acid.....	25	(?)	379	1.55 × 10 <sup>-4</sup>	(27)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	$\Delta^{2,6}$ -Dihydrophthalic acid.....	25	0.03-0.001	379	5.45 × 10 <sup>-4</sup>	(2)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	$\Delta^{2,6}$ -Dihydrophthalic acid.....	25	0.016-0.001	379	1.62 × 10 <sup>-4</sup>	(524); cf. (28)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	<i>trans</i> - $\Delta^{3,5}$ -Dihydrophthalic acid...	25	(?)	379	2.46 × 10 <sup>-4</sup>	(27)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	Dimethylpyronecarboxylic acid...	25	0.02-0.003	378	3.85 × 10 <sup>-4</sup>	(181)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	Guaiacolcarboxylic acid.....	25	0.016-0.001	380	1.35 × 10 <sup>-3</sup>	(323, 378)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	Orsellic acid.....	25	0.008-0.001	380	1.3 × 10 <sup>-4</sup>	(260)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	<i>p</i> -Orsellic acid.....	25	0.008-0.001	380	3.8 × 10 <sup>-3</sup>	(260, 436)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	2-Methylpyrone-6-acetic acid.....	(?)	(?)	(?)	1.52 × 10 <sup>-5</sup>	(130)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	Vanillic acid.....	25	0.016-0.001	380	2.94 × 10 <sup>-6</sup>	(436); cf. (378)
		0-65	0.004-0.0005			(526)
C <sub>8</sub> H <sub>5</sub> O <sub>4</sub>	Isovanillic acid.....	25	0.004-0.001	380	3.1 × 10 <sup>-5</sup>	(436)
C <sub>8</sub> H <sub>5</sub> O <sub>5</sub>	Methyl gallate.....	25	0.03-0.004	377	9 × 10 <sup>-3</sup>	(135)
C <sub>8</sub> H <sub>5</sub> O <sub>5</sub>	Hematinic acid anhydride.....	25	0.05-0.0008	379	2.25 × 10 <sup>-4</sup>	(333)
C <sub>8</sub> H <sub>5</sub> O <sub>5</sub>	Hydroxydehydroacetic acid.....	25	0.002-0.0004	380	1.6 × 10 <sup>-3</sup>	(182)
C <sub>8</sub> H <sub>5</sub> O <sub>5</sub> S	$\alpha$ -Monomethyl <i>m</i> -sulfobenzoate...	25	0.004-0.003	377	7 × 10 <sup>-4</sup>	(598)
C <sub>8</sub> H <sub>5</sub> O <sub>5</sub> S	$\alpha$ -Monomethyl <i>p</i> -sulfobenzoate...	25	0.0009	380	[7.2 × 10 <sup>-4</sup> ]	(601)
C <sub>8</sub> H <sub>5</sub> O <sub>5</sub> S	$\beta$ -Monomethyl <i>m</i> -sulfobenzoate...	25	0.02-0.0007	377	$\Delta_{0.02} = 345$	(598)
C <sub>8</sub> H <sub>5</sub> NO	Acetophenoneoxime.....	25	0.008-0.001	380	3.7 × 10 <sup>-9</sup>	(557); cf. (226)
C <sub>8</sub> H <sub>5</sub> NO <sub>2</sub>	<i>o</i> -Methylaminobenzoic acid.....	25	0.0013-0.0007	380	4.5 × 10 <sup>-6</sup>	(140)
C <sub>8</sub> H <sub>5</sub> NO <sub>2</sub>	<i>m</i> -Methylaminobenzoic acid.....	25	0.012-0.0008	379	7 × 10 <sup>-6</sup>	(140)
C <sub>8</sub> H <sub>5</sub> NO <sub>2</sub>	<i>p</i> -Methylaminobenzoic acid.....	25	0.008-0.001	379	9.0 × 10 <sup>-6</sup>	(297)
C <sub>8</sub> H <sub>5</sub> NO <sub>2</sub>	Phenylaminoacetic acid.....	25	0.03-0.001	378	3.8 × 10 <sup>-5</sup>	(436, 579)
C <sub>8</sub> H <sub>5</sub> NO <sub>3</sub>	Anishydroxamic acid.....	25	0.008-0.002	380	7.3 × 10 <sup>-7</sup>	(426)
C <sub>8</sub> H <sub>5</sub> NO <sub>4</sub>	2, 4-Dimethylpyrrole-3, 5-dicarboxylic acid.....	25	0.0008-0.0004	380	2.0 × 10 <sup>-3</sup>	(7)
C <sub>8</sub> H <sub>5</sub> NO <sub>4</sub>	2, 5-Dimethylpyrrole-3, 4-dicarboxylic acid.....	25	0.0008-0.0002	378	$\Delta_{0.0008} = 345$	(7)
C <sub>8</sub> H <sub>5</sub> NO <sub>4</sub>	Hematinic imide.....	25	0.05-0.0008	376	[3.63 × 10 <sup>-5</sup> ]	(333); cf. (336)
C <sub>8</sub> H <sub>5</sub> NO <sub>4</sub> S	Benzenesulfoneaminoacetic acid...	25	0.016-0.001	376	3.46 × 10 <sup>-4</sup>	(358)
C <sub>8</sub> H <sub>10</sub> N <sub>2</sub> O	<i>O</i> -Methyl- <i>N</i> -phenylpseudourea...	25	0.12-0.004	226	2.5 × 10 <sup>-7</sup>	(107)
C <sub>8</sub> H <sub>10</sub> N <sub>2</sub> O <sub>2</sub> S	Nitrodimethylanilinesulfonic acid...	25	0.03-0.001	379	$\Delta_{0.02} = 88.4$	(165)
C <sub>8</sub> H <sub>10</sub> N <sub>2</sub> O <sub>2</sub>	Caffeine.....	25	0.05-0.02	(?)	$\Delta_{0.05} = 0.15$	(392)
C <sub>8</sub> H <sub>10</sub> O	1, 3-Dimethyl-4-hydroxybenzene...	25	0.014-0.004	381	3 × 10 <sup>-5</sup>	(26)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub> S	<i>p</i> -Tolubenzylsulfonic acid.....	25	0.12-0.001	376	$\Delta_{0.05} = 356$	(143)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub> S	1, 4-Xylene-2-sulfonic acid.....	25	0.12-0.001	376	$\Delta_{0.02} = 362$	(143)
C <sub>8</sub> H <sub>10</sub> O <sub>4</sub>	$\beta$ -Mesityloxide oxalic acid.....	(?)	(?)	(?)	1 × 10 <sup>-2</sup>	(155)
C <sub>8</sub> H <sub>10</sub> O <sub>4</sub>	<i>trans</i> - $\Delta^1$ -Tetrahydrophthalic acid...	25	(?)	379	5.9 × 10 <sup>-4</sup>	(27)
C <sub>8</sub> H <sub>10</sub> O <sub>4</sub>	$\Delta^1$ -Tetrahydroterephthalic acid...	25	0.003-0.0004	378	5.0 × 10 <sup>-5</sup>	(524)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>8</sub> H <sub>10</sub> O <sub>4</sub>	Δ <sup>1</sup> -Tetrahydrophthalic acid.....	25	0.016-0.001	378	7.4 × 10 <sup>-5</sup>	(524); cf. (28)
C <sub>8</sub> H <sub>10</sub> O <sub>4</sub>	Δ <sup>1</sup> -Tetrahydrophthalic acid.....	25	0.03-0.0001	380	5.70 × 10 <sup>-4</sup>	(1)
C <sub>8</sub> H <sub>10</sub> O <sub>4</sub>	cis-Δ <sup>4</sup> -Tetrahydrophthalic acid....	25	(?)	379	6.2 × 10 <sup>-4</sup>	(3)
C <sub>8</sub> H <sub>10</sub> O <sub>4</sub>	trans-Δ <sup>4</sup> -Tetrahydrophthalic acid..	25	(?)	379	1.18 × 10 <sup>-4</sup>	(27)
					1.30 × 10 <sup>-4</sup>	(3)
C <sub>8</sub> H <sub>10</sub> O <sub>8</sub>	α-Butanetetracarboxylic acid.....	25	0.03-0.001	376	3.95 × 10 <sup>-4</sup>	(292, 578)
C <sub>8</sub> H <sub>10</sub> O <sub>8</sub>	β-Butanetetracarboxylic acid.....	25	0.03-0.002	376	4.1 × 10 <sup>-4</sup>	(23, 292)
					8 × 10 <sup>-4</sup>	(578)
C <sub>8</sub> H <sub>10</sub> O <sub>8</sub>	Diacetyltartaric acid.....	25	0.85-0.001	379	Δ <sub>0.08</sub> = 229	(147, 577)
C <sub>8</sub> H <sub>11</sub> N	2, 4, 6-Trimethylpyridine.....	10	0.10-0.007	171	1.22 × 10 <sup>-7</sup>	(363)
		15	0.10-0.007	191	1.42 × 10 <sup>-7</sup>	(363)
		25	0.10-0.007	229	2.05 × 10 <sup>-7</sup>	(363)
		25	0.11-0.014			(207)
		40	0.10-0.007	290	3.05 × 10 <sup>-7</sup>	(363)
		50	0.10-0.007	330	3.75 × 10 <sup>-7</sup>	(363)
C <sub>8</sub> H <sub>11</sub> NO <sub>3</sub>	Propyl cyanoacetoacetate.....	25	0.008-0.001	378	5.7 × 10 <sup>-4</sup>	(214)
C <sub>8</sub> H <sub>11</sub> NO <sub>3</sub>	Methyl cyanobutyrylacetate.....	25	0.008-0.001	377	6.1 × 10 <sup>-4</sup>	(214)
C <sub>8</sub> H <sub>11</sub> NO <sub>3</sub>	Methyl cyanoisobutyrylacetate....	25	0.002-0.001	377	4.9 × 10 <sup>-4</sup>	(214)
C <sub>8</sub> H <sub>11</sub> NO <sub>3</sub>	Dimethylviolanilic acid.....	25	0.03-0.004	378	3.94 × 10 <sup>-6</sup>	(348)
C <sub>8</sub> H <sub>11</sub> NO <sub>3</sub> S	Dimethylaniline-4-sulfonic acid...	25	0.06-0.002	376	3.68 × 10 <sup>-4</sup>	(165)
C <sub>8</sub> H <sub>11</sub> NO <sub>3</sub> S	Ethylaniline-3-sulfonic acid.....	25	0.03-0.001	379	1.59 × 10 <sup>-4</sup>	(205)
C <sub>8</sub> H <sub>11</sub> NO <sub>3</sub> S	Ethylaniline-4-sulfonic acid.....	25	0.03-0.001	379	1.25 × 10 <sup>-4</sup>	(205)
C <sub>8</sub> H <sub>11</sub> NO <sub>3</sub> S	1, 4, 2-Xylidine-5-sulfonic acid....	25	0.016-0.001	379	4.32 × 10 <sup>-4</sup>	(436)
C <sub>8</sub> H <sub>11</sub> NO <sub>4</sub>	Diethyl cyanomalonate.....	25	0.016-0.0005	376	Δ <sub>0.016</sub> = 283	(213)
C <sub>8</sub> H <sub>11</sub> N <sub>2</sub>	Dimethyl-p-phenylenediamine....	25	0.08	(?)	Δ <sub>0.08</sub> > 0.19	(230)
C <sub>8</sub> H <sub>12</sub> N <sub>2</sub> O <sub>3</sub>	5, 5-Diethylbarbituric acid.....	25	0.016	378	3.7 × 10 <sup>-8</sup>	(624)
C <sub>8</sub> H <sub>12</sub> O <sub>2</sub>	1-Cycloheptene-1-carboxylic acid..	25	0.004-0.001	379	9.8 × 10 <sup>-6</sup>	(486)
					8.2 × 10 <sup>-6</sup>	(616)
C <sub>8</sub> H <sub>12</sub> O <sub>2</sub>	2-Cycloheptene-1-carboxylic acid..	25	0.016-0.002	379	2.60 × 10 <sup>-6</sup>	(486)
C <sub>8</sub> H <sub>12</sub> O <sub>2</sub>	Cyclohexeneacetic acid (liquid isomer).....	25	0.02-0.001	378	2.55 × 10 <sup>-6</sup>	(635)
C <sub>8</sub> H <sub>12</sub> O <sub>2</sub>	Cyclohexeneacetic acid (solid isomer).....	25	0.02-0.001	378	2.45 × 10 <sup>-6</sup>	(635)
C <sub>8</sub> H <sub>12</sub> O <sub>2</sub>	Dimethyldihydroresorcinol.....	25	0.016-0.001	377	7.1 × 10 <sup>-6</sup>	(508)
C <sub>8</sub> H <sub>12</sub> O <sub>3</sub>	Heptic acid.....	25	0.008-0.002	376	8.2 × 10 <sup>-6</sup>	(569)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	Isobutylyfumaric acid.....	25	0.008-0.001	378	9.1 × 10 <sup>-4</sup>	(577)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	Ethyl diacetoacetate.....	25	0.008	(?)	[Δ <sub>0.008</sub> = 3.5]	(213)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	Dicrotonic acid.....	25	(?)	(?)	2.3 × 10 <sup>-6</sup>	(443)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	cis-Hexahydrophthalic acid.....	25	(?)	378	4.4 × 10 <sup>-6</sup>	(27)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	trans-Hexahydrophthalic acid.....	25	(?)	378	6.2 × 10 <sup>-6</sup>	(27)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	cis-Hexahydroterephthalic acid...	25	0.015-0.0005	377	2.91 × 10 <sup>-6</sup>	(524)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	trans-Hexahydroterephthalic acid..	25	0.005-0.0006	377	4.48 × 10 <sup>-6</sup>	(524)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	meso-Methylallylsuccinic acid....	25	0.06-0.0005	377	2.28 × 10 <sup>-4</sup>	(268)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	p-Methylallylsuccinic acid.....	25	0.06-0.0005	377	2.40 × 10 <sup>-4</sup>	(268)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	γ-Methyl-γ-ethylidenepyrotartaric acid.....	25	0.02-0.0007	376	1.10 × 10 <sup>-4</sup>	(530)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	Methylethylitaconic acid.....	25	0.007-0.0005	377	1.47 × 10 <sup>-4</sup>	(524)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	Methylpropylmaleic acid.....	25	0.016-0.001	379	7.2 × 10 <sup>-5</sup>	(335)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	Methylisopropylmaleic acid.....	25	0.016-0.001	379	1.5 × 10 <sup>-4</sup>	(335)
C <sub>8</sub> H <sub>12</sub> O <sub>6</sub>	α, α-Dimethyltricarballic acid...	25	0.04-0.005	375	3.15 × 10 <sup>-4</sup>	(98)
C <sub>8</sub> H <sub>12</sub> O <sub>6</sub>	α, α'-Dimethyltricarballic acid (a acid, M. P. 206-7°).....	25	0.03-0.004	377	4.3 × 10 <sup>-4</sup>	(98, 630)
C <sub>8</sub> H <sub>12</sub> O <sub>6</sub>	α, α'-Dimethyltricarballic acid (b acid, M. P., 174°).....	25	0.05-0.006	377	5.4 × 10 <sup>-4</sup>	(98, 630)
C <sub>8</sub> H <sub>12</sub> O <sub>6</sub>	α, α'-Dimethyltricarballic acid (c acid, M. P., 148°).....	25	0.05-0.006	377	5.6 × 10 <sup>-4</sup>	(98)
					5.1 × 10 <sup>-4</sup>	(630)
C <sub>8</sub> H <sub>12</sub> O <sub>6</sub>	Ethyltricarballic acid.....	25	0.03-0.001	376	3.1 × 10 <sup>-4</sup>	(578)
C <sub>8</sub> H <sub>12</sub> O <sub>6</sub>	Hemotricarboxylic acid:					
	(a) M. P., 140-141°.....	25	0.03-0.001	378	[2.48 × 10 <sup>-4</sup> ]	(334, 337)
	(b) M. P., 175-176°.....	25	0.03-0.001	378	[2.44 × 10 <sup>-4</sup> ]	(334, 337)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		$t, ^\circ\text{C}$	c-Range	$\Delta_0$	$k(\text{or } \Delta_c)$	Lit.
Formula	Name					
$\text{C}_3\text{H}_7\text{NO}_2$	Tropic acid.....	25	0.03–0.001	377	$4.2 \times 10^{-4}$	(618)
$\text{C}_7\text{H}_{14}\text{O}_2$	Cycloheptanecarboxylic acid.....	25	0.004–0.001	378	$1.20 \times 10^{-3}$	(635)
$\text{C}_6\text{H}_{12}\text{O}_2$	Cyclohexanecarboxylic acid.....	25	0.005–0.0009	378	$2.32 \times 10^{-3}$	(635)
$\text{C}_8\text{H}_{16}\text{O}_2$	1-Ethylpentamethylene-2-carboxylic acid.....	25	0.015–0.001	378	$1.09 \times 10^{-3}$	(635)
$\text{C}_8\text{H}_{16}\text{O}_2$	1-Methylcyclohexane-1-carboxylic acid.....	25	0.008–0.001	378	$6.8 \times 10^{-3}$	(635)
$\text{C}_8\text{H}_{16}\text{O}_2$	<i>cis</i> -1-Methylcyclohexane-2-carboxylic acid.....	25	0.005–0.0006	378	$1.61 \times 10^{-3}$	(635)
$\text{C}_8\text{H}_{16}\text{O}_2$	<i>trans</i> -1-Methylcyclohexane-2-carboxylic acid.....	25	0.02–0.0006	378	$2.01 \times 10^{-3}$	(635)
$\text{C}_8\text{H}_{16}\text{O}_2$	1-Methylcyclohexane-3-carboxylic acid.....	25	0.02–0.001	378	$1.26 \times 10^{-3}$	(635)
$\text{C}_8\text{H}_{16}\text{O}_2$	1-Methylcyclohexane-4-carboxylic acid.....	25	0.005–0.0006	378	$1.09 \times 10^{-3}$	(635)
$\text{C}_8\text{H}_{16}\text{O}_2$	Ethyl ethylacetate.....	25	0.008–0.004	(?)	$\Delta_{0.008} = 0.07$	(569)
$\text{C}_8\text{H}_{16}\text{O}_2$	Monoethyl adipate.....	25	0.01–0.0007	375	$2.5 \times 10^{-3}$	(582)
$\text{C}_8\text{H}_{16}\text{O}_2$	Isoamylmalonic acid.....	25	0.06–0.001	377	$1.22 \times 10^{-3}$	(390)
$\text{C}_8\text{H}_{16}\text{O}_2$	Isobutylsuccinic acid.....	25	0.03–0.001	377	$8.65 \times 10^{-4}$	(569, 577)
$\text{C}_8\text{H}_{16}\text{O}_2$	Diethylsuccinic acid.....	25	0.03–0.001	377	$3.79 \times 10^{-4}$	(577)
$\text{C}_8\text{H}_{16}\text{O}_2$	<i>fum.-sym.</i> -Diethylsuccinic acid.....	25	0.03–0.001	377	$2.32 \times 10^{-4}$	(139, 577, 631)
$\text{C}_8\text{H}_{16}\text{O}_2$	<i>mal.-sym.</i> -Diethylsuccinic acid.....	25	0.03–0.0007	377	$3.41 \times 10^{-4}$	(139, 577, 631)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\alpha$ - <i>sym.</i> -Dimethyladipic acid.....	25	0.02–0.002	377	$4.1 \times 10^{-3}$	(631)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\beta$ - <i>sym.</i> -Dimethyladipic acid.....	25	0.04–0.003	377	$4.1 \times 10^{-3}$	(631)
$\text{C}_8\text{H}_{16}\text{O}_2$	Dimethylethylsuccinic acid.....	25	0.03–0.001	377	$5.50 \times 10^{-4}$	(97, 577)
$\text{C}_8\text{H}_{16}\text{O}_2$	Dimethyl- <i>H</i> -ethylsuccinic acid.....	25	0.03–0.002	376	$5.7 \times 10^{-3}$	(60)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\alpha$ -Ethyladipic acid.....	24.2	0.02–0.0013	374	$4.0 \times 10^{-3}$	(391)
$\text{C}_8\text{H}_{16}\text{O}_2$	Ethylpropylmalonic acid.....	25	0.06–0.001	375	$8.9 \times 10^{-3}$	(390, 525)
$\text{C}_8\text{H}_{16}\text{O}_2$	Ethylisopropylmalonic acid.....	25	0.03–0.001	375	$1.05 \times 10^{-3}$	(390)
$\text{C}_8\text{H}_{16}\text{O}_2$	Methylbutylmalonic acid.....	25	0.06–0.001	375	$1.80 \times 10^{-3}$	(390)
$\text{C}_8\text{H}_{16}\text{O}_2$	Methylisobutylmalonic acid.....	25	0.03–0.001	375	$3.0 \times 10^{-3}$	(390)
$\text{C}_8\text{H}_{16}\text{O}_2$	<i>meso</i> - $\alpha$ -Methyl- $\alpha'$ -ethylglutaric acid.....	25	0.03–0.001	377	$5.5 \times 10^{-3}$	(60, 577)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\beta$ -Methyl- $\alpha$ -ethylglutaric acid.....	(?)	(?)	(?)	$6.7 \times 10^{-3}$	(443)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\beta$ -Methyl- $\beta$ -ethylglutaric acid.....	25	0.03–0.001	(?)	$2.44 \times 10^{-4}$	(525.2)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\alpha$ -Methylpimelic acid.....	(?)	(?)	(?)	$3.15 \times 10^{-3}$	(633)
$\text{C}_8\text{H}_{16}\text{O}_2$	<i>cis-sym.</i> -Methylisopropylsuccinic acid.....	25	0.01–0.0014	375	$6.6 \times 10^{-4}$	(96)
$\text{C}_8\text{H}_{16}\text{O}_2$	<i>trans-sym.</i> -Methylisopropylsuccinic acid.....	25	0.006–0.0008	375	$1.56 \times 10^{-4}$	(96)
$\text{C}_8\text{H}_{16}\text{O}_2$	<i>cis</i> - $\alpha, \alpha'$ -Methylpropylsuccinic acid.....	25	0.008–0.001	375	$2.95 \times 10^{-4}$	(96)
$\text{C}_8\text{H}_{16}\text{O}_2$	<i>trans</i> - $\alpha, \alpha'$ -Methylpropylsuccinic acid.....	25	0.004–0.0005	375	$1.45 \times 10^{-4}$	(96)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\alpha$ -Propylglutaric acid.....	24.4	0.016–0.001	375	$5.8 \times 10^{-3}$	(391)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\alpha$ -Isopropylglutaric acid.....	25	0.05–0.0009	377	$5.40 \times 10^{-3}$	(8, 391)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\beta$ -Isopropylglutaric acid.....	[25]	(?)	(?)	$6.46 \times 10^{-4}$	(289)
$\text{C}_8\text{H}_{16}\text{O}_2$	Suberic acid.....	25	0.016–0.0005	377	$2.96 \times 10^{-3}$	(49, 139, 524, 565); cf. (59, 436)
$\text{C}_8\text{H}_{16}\text{O}_2$	Tetramethylsuccinic acid.....	25	0.012–0.0005	376	$3.08 \times 10^{-4}$	(49, 61, 139, 561)
$\text{C}_8\text{H}_{16}\text{O}_2$	Monomethyl trimethylsuccinate.....	25	0.06–0.007	375	$2.65 \times 10^{-3}$	(100)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\alpha, \alpha, \alpha'$ -Trimethylglutaric acid.....	25	0.01–0.0007	376	$3.4 \times 10^{-3}$	(49, 61)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\alpha, \beta, \beta$ -Trimethylglutaric acid.....	25	0.03–0.001	377	$1.44 \times 10^{-4}$	(30)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\alpha$ -Dimethyldihydroxyadipic acid.....	(?)	(?)	(?)	$3.17 \times 10^{-4}$	(634)
$\text{C}_8\text{H}_{16}\text{O}_2$	$\gamma$ -Dimethyldihydroxyadipic acid.....	(?)	(?)	(?)	$3.30 \times 10^{-4}$	(634)
$\text{C}_8\text{H}_{16}\text{NO}$	Tropine.....	10	0.06–0.01	170	$1.87 \times 10^{-4}$	(365)
		25	0.06–0.01	227	$2.74 \times 10^{-4}$	(365)
		50	0.06–0.01	326	$3.89 \times 10^{-4}$	(365)
$\text{C}_8\text{H}_{16}\text{O}_2$	Caprylic acid.....	25	0.004–0.001	377	$1.41 \times 10^{-3}$	(200)
		0–65	0.002–0.0005			(610, 611)
$\text{C}_8\text{H}_{16}\text{O}_2$	Diisopropylglycolic acid.....	25	0.03–0.001	376	$1.27 \times 10^{-4}$	(550)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>2</sub> H <sub>16</sub> O <sub>3</sub>	α-Dimethyl-β-isopropylethylene-lactic acid.....	25	0.03-0.0009	376	2.16 × 10 <sup>-6</sup>	(550)
C <sub>2</sub> H <sub>16</sub> O <sub>3</sub>	α-Hydroxycaprylic acid.....	25	0.008-0.0005	377	1.55 × 10 <sup>-4</sup>	(88)
C <sub>2</sub> H <sub>17</sub> N	d-Coniine.....	25	0.06-0.004	226	1.05 × 10 <sup>-3</sup>	(104, 392, 629)
C <sub>2</sub> H <sub>19</sub> N	Diisobutylamine.....	25	0.016-0.004	225	3.9 × 10 <sup>-4</sup>	(104)
C <sub>2</sub> H <sub>21</sub> NO	Tetraethylammonium hydroxide..	25	0.06-0.004	230	Λ <sub>0.06</sub> = 188	(433)
C <sub>2</sub> H <sub>5</sub> NO <sub>2</sub>	Isonitrosodiketohydrindene.....	25	0.006-0.001	378	1.8 × 10 <sup>-6</sup>	(235)
					1.0 × 10 <sup>-6</sup>	(379)
C <sub>2</sub> H <sub>5</sub> NO <sub>4</sub>	α-Nitrophenylpropionic acid.....	25	0.004-0.001	376	1.01 × 10 <sup>-2</sup>	(436)
C <sub>2</sub> H <sub>5</sub> NO <sub>4</sub>	Pyridine-2, 3, 4, 5-tetracarboxylic acid.....	25	0.004-0.0002	(?)	Λ <sub>0.004</sub> = 497	(436)
C <sub>2</sub> H <sub>6</sub> N <sub>2</sub> O <sub>2</sub>	Benzoylpseudo-α, β'-furazane.....	25	0.005-0.001	378	3.2 × 10 <sup>-2</sup>	(80)
C <sub>2</sub> H <sub>6</sub> N <sub>2</sub> O <sub>2</sub>	Phenylazoxazolecarboxylic acid...	25	0.016-0.002	376	3 × 10 <sup>-2</sup>	(244)
C <sub>2</sub> H <sub>6</sub> N <sub>2</sub> O <sub>2</sub>	Phenylloximino-syn-oxazolone.....	25	0.002-0.001	376	1.85 × 10 <sup>-4</sup>	(244)
C <sub>2</sub> H <sub>6</sub> O <sub>2</sub>	Phenylpropionic acid.....	25	0.016-0.001	378	5.8 × 10 <sup>-3</sup>	(436)
		0-65	0.008-0.0005			(526)
C <sub>2</sub> H <sub>6</sub> O <sub>6</sub>	Phthalonic acid.....	25	0.20-0.001	378	2.5 × 10 <sup>-3</sup>	(69, 540)
C <sub>2</sub> H <sub>6</sub> O <sub>6</sub>	Trimellitic acid.....	25	0.03-0.001	378	3.2 × 10 <sup>-3</sup>	(601)
C <sub>2</sub> H <sub>6</sub> O <sub>6</sub>	Trimesic acid.....	25	0.02-0.0006	378	Λ <sub>0.009</sub> = 91.0	(49)
C <sub>2</sub> H <sub>7</sub> BrO <sub>2</sub>	α-Bromocinnamic acid.....	25	0.002-0.0005	378	9.1 × 10 <sup>-4</sup>	(436)
C <sub>2</sub> H <sub>7</sub> BrO <sub>2</sub>	β-Bromocinnamic acid.....	25	0.009-0.001	378	1.4 × 10 <sup>-2</sup>	(436)
		25-99	0.008-0.001			(506)
C <sub>2</sub> H <sub>7</sub> BrO <sub>4</sub>	1-Monomethyl 2-bromoterephthalate.....	25	0.002-0.0005	378	3.7 × 10 <sup>-4</sup>	(598)
C <sub>2</sub> H <sub>7</sub> BrO <sub>4</sub>	4-Monomethyl 2-bromoterephthalate.....	25	0.004-0.001	378	5 × 10 <sup>-3</sup>	(598)
C <sub>2</sub> H <sub>7</sub> Br <sub>2</sub> FO <sub>2</sub>	α, β-Dibromo-α-fluorohydrocinnamic acid.....	25	0.016-0.002	374	Λ <sub>0.016</sub> = 347.7	(546)
C <sub>2</sub> H <sub>7</sub> ClO <sub>2</sub>	β-Chloroallocinnamic acid.....	25	0.0014-0.0007	377	2.8 × 10 <sup>-4</sup>	(412)
C <sub>2</sub> H <sub>7</sub> ClO <sub>2</sub>	β-Chlorocinnamic acid.....	25	0.003-0.0007	377	2.7 × 10 <sup>-4</sup>	(412)
C <sub>2</sub> H <sub>7</sub> ClO <sub>2</sub>	1'-Chlorocinnamic acid.....	25	0.005-0.0012	377	1.1 × 10 <sup>-2</sup>	(412)
C <sub>2</sub> H <sub>7</sub> ClO <sub>2</sub>	1 <sup>2</sup> -Chlorocinnamic acid.....	25	0.004-0.0005	377	1.0 × 10 <sup>-3</sup>	(412)
C <sub>2</sub> H <sub>7</sub> FO <sub>2</sub>	α-Fluorocinnamic acid.....	25	0.004-0.001	375	1.9 × 10 <sup>-3</sup>	(546)
C <sub>2</sub> H <sub>7</sub> IO <sub>2</sub>	α-Iodoallocinnamic acid.....	[25]	0.001-0.0006	377	5.8 × 10 <sup>-6</sup>	(294)
C <sub>2</sub> H <sub>7</sub> IO <sub>2</sub>	β-Iodoallocinnamic acid.....	[25]	0.0004	377	2.3 × 10 <sup>-6</sup>	(294)
C <sub>2</sub> H <sub>7</sub> IO <sub>2</sub>	α-Iodocinnamic acid.....	[25]	0.0009-0.0004	377	5.0 × 10 <sup>-6</sup>	(294)
C <sub>2</sub> H <sub>7</sub> IO <sub>2</sub>	β-Iodocinnamic acid.....	[25]	0.001-0.0007	377	4.0 × 10 <sup>-6</sup>	(294)
C <sub>2</sub> H <sub>7</sub> NO <sub>2</sub>	Pr-2-(α)-Indolecarboxylic acid....	25	0.006-0.0007	377	1.74 × 10 <sup>-4</sup>	(7)
C <sub>2</sub> H <sub>7</sub> NO <sub>2</sub>	Pr-3-(β)-Indolecarboxylic acid....	25	0.0014-0.0004	377	5.4 × 10 <sup>-6</sup>	(7)
C <sub>2</sub> H <sub>7</sub> NO <sub>2</sub>	Phenyl-syn-oxazolone.....	25	0.002-0.001	378	5.3 × 10 <sup>-6</sup>	(244)
C <sub>2</sub> H <sub>7</sub> NO <sub>2</sub>	2, 3, 4-Trihydroxyquinoline.....	25	0.0008	(?)	Λ <sub>0.0008</sub> = 2.1	(569)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	1-Trimellitamic acid.....	25	0.03-0.0005	378	4.4 × 10 <sup>-4</sup>	(601)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	2-Trimellitamic acid.....	25	0.03-0.0005	378	7.5 × 10 <sup>-4</sup>	(601)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub> S	o-Benzoylsulfoglycine.....	25	0.03-0.001	(?)	[Λ <sub>0.03</sub> = 0.09]	(374)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub> S	Mono-(C)-methyl sulfimidephthalate.....	25	0.025	375	3.1 × 10 <sup>-2</sup>	(637)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub> S	Mono-(N)-methyl sulfimidephthalate.....	25	0.025	375	3.8 × 10 <sup>-3</sup>	(637)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	2-Methylpyridine-3, 5, 6-tricarboxylic acid.....	25	0.008-0.0002	(?)	Λ <sub>0.008</sub> = 298	(436)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	4-Methylpyridine-3, 5, 6-tricarboxylic acid.....	25	0.008-0.0002	(?)	Λ <sub>0.008</sub> = 365	(436)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	1-Monomethyl 2-nitroterephthalate	25	0.004-0.001	377	7.6 × 10 <sup>-4</sup>	(598)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	4-Monomethyl 2-nitroterephthalate	25	0.016-0.001	377	1.9 × 10 <sup>-2</sup>	(598)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	1-Monomethyl 3-nitrophthalate...	25	0.016-0.001	377	1.6 × 10 <sup>-2</sup>	(598)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	2-Monomethyl 3-nitrophthalate...	25	0.008-0.001	377	2.0 × 10 <sup>-3</sup>	(598)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	1-Monomethyl 4-nitroisophthalate	25	0.004-0.001	377	1.05 × 10 <sup>-2</sup>	(601)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	3-Monomethyl 4-nitroisophthalate	25	0.002-0.0005	377	8.3 × 10 <sup>-4</sup>	(601)
C <sub>2</sub> H <sub>7</sub> NO <sub>6</sub>	?-Monomethyl 4-nitrophthalate..	25	0.016-0.001	377	4.6 × 10 <sup>-3</sup>	(598)
C <sub>2</sub> H <sub>7</sub> N <sub>3</sub> O <sub>2</sub>	C-Phenylosotriazolecarboxylic acid	20	0.004	(?)	Λ <sub>0.004</sub> = 94.9	(429)
		0-40	0.004			(429)
C <sub>2</sub> H <sub>4</sub> BrClO <sub>4</sub>	Ethyl 2-chloro-6-bromogallate....	25	0.03-0.004	373	2 × 10 <sup>-6</sup>	(135)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	$\alpha$ -Range	$\Delta_0$	<i>k</i> (or $\Delta_c$ )	Lit.
Formula	Name					
C <sub>9</sub> H <sub>8</sub> Br <sub>2</sub> O <sub>6</sub>	Ethyl dibromogallate.....	25	0.016-0.002	374	1.5 × 10 <sup>-6</sup>	(135)
C <sub>9</sub> H <sub>8</sub> Cl <sub>2</sub> O <sub>6</sub>	Dichloroveratric acid.....	25	0.001-0.0002	376	[1 × 10 <sup>-3</sup> ]	(135)
C <sub>9</sub> H <sub>8</sub> Cl <sub>2</sub> O <sub>6</sub>	Ethyl 2, 6-dichlorogallate.....	25	0.03-0.004	374	4.1 × 10 <sup>-7</sup>	(135)
C <sub>9</sub> H <sub>8</sub> N <sub>2</sub> O <sub>2</sub>	<i>m</i> -Methyl- $\alpha$ -benzimidazolecarboxylic acid.....	[25]	0.005-0.0013	(?)	1.07 × 10 <sup>-6</sup>	(33)
C <sub>9</sub> H <sub>8</sub> N <sub>2</sub> O <sub>2</sub>	$\alpha$ -Methyl- <i>m</i> -benzimidazolecarboxylic acid.....	25	0.0014-0.0007	375	1.00 × 10 <sup>-6</sup>	(26)
C <sub>9</sub> H <sub>8</sub> N <sub>2</sub> O <sub>4</sub>	Phthaluric acid.....	25	0.016-0.001	376	2.84 × 10 <sup>-4</sup>	(436)
C <sub>9</sub> H <sub>8</sub> N <sub>2</sub> O <sub>6</sub>	2, 3-Dimethoxy-5, 6-dinitrobenzoic acid.....	25	0.004-0.001	376	4.4 × 10 <sup>-2</sup>	(601)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	Atropic acid.....	25	0.008-0.0005	378	1.40 × 10 <sup>-4</sup>	(436)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	Cinnamic acid.....	25	0.004-0.0004	378	3.51 × 10 <sup>-6</sup>	(169, 436)
					3.65 × 10 <sup>-5</sup>	(488)
		0-99	0.002-0.0005			(506, 526, 609)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	Allocinnamic acid (M. P., 68°)...	25	0.02-0.001	378	1.39 × 10 <sup>-4</sup>	(51, 347); cf. (359, 488)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	Isocinnamic acid (M. P., 42°).....	25	0.02-0.001	378	1.35 × 10 <sup>-4</sup>	(51, 345, 396, 399)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	Isocinnamic acid (M. P., 58°).....	25	0.02-0.001	378	1.38 × 10 <sup>-4</sup>	(51, 399); cf. (26, 436)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	<i>hetero-<math>\alpha</math></i> -Cinnamic acid.....	25	0.003-0.0004	378	3.5 × 10 <sup>-5</sup>	(168)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	<i>hetero-<math>\beta</math></i> -Cinnamic acid.....	25	0.003-0.0004	378	3.53 × 10 <sup>-5</sup>	(168)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	<i>stear-<math>\alpha</math></i> -Cinnamic acid.....	25	0.003-0.0008	378	3.56 × 10 <sup>-5</sup>	(168)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	<i>stear-<math>\beta</math></i> -Cinnamic acid.....	25	0.004-0.0004	378	3.6 × 10 <sup>-5</sup>	(168)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	<i>o</i> -Coumaric acid.....	25	0.004-0.001	378	2.4 × 10 <sup>-5</sup>	(378); cf. (436)
		0-65	0.004-0.0005			(526)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	<i>allo-p</i> -Coumaric acid.....	25	0.024-0.002	378	8.0 × 10 <sup>-6</sup>	(488)
C <sub>9</sub> H <sub>8</sub> O <sub>2</sub>	<i>p</i> -Coumaric acid.....	25	0.008-0.001	378	2.14 × 10 <sup>-6</sup>	(436)
					2.25 × 10 <sup>-6</sup>	(488)
C <sub>9</sub> H <sub>8</sub> O <sub>4</sub>	<i>o</i> -Acetoxybenzoic acid.....	25	0.016-0.001	377	3.3 × 10 <sup>-4</sup>	(436)
		0-50	0.008-0.0005			(526)
C <sub>9</sub> H <sub>8</sub> O <sub>4</sub>	<i>m</i> -Acetoxybenzoic acid.....	25	0.004-0.001	377	9.68 × 10 <sup>-5</sup>	(436)
		0-35	0.008-0.0005			(526)
C <sub>9</sub> H <sub>8</sub> O <sub>4</sub>	<i>p</i> -Acetoxybenzoic acid.....	25	0.016-0.001	377	4.15 × 10 <sup>-5</sup>	(436)
C <sub>9</sub> H <sub>8</sub> O <sub>4</sub>	Homophthalic acid.....	25	0.03-0.001	378	1.88 × 10 <sup>-4</sup>	(156, 540)
C <sub>9</sub> H <sub>8</sub> O <sub>4</sub>	Monomethyl phthalate.....	25	0.01-0.0012	377	6.55 × 10 <sup>-4</sup>	(582)
C <sub>9</sub> H <sub>8</sub> O <sub>4</sub>	Monomethylisophthalate.....	25	0.002-0.0005	378	1.28 × 10 <sup>-4</sup>	(601)
C <sub>9</sub> H <sub>8</sub> O <sub>4</sub>	Umbellic acid.....	25	0.008-0.001	378	1.85 × 10 <sup>-5</sup>	(436)
C <sub>9</sub> H <sub>8</sub> O <sub>4</sub>	<i>sym.</i> -Uvitic acid.....	25	0.004-0.0005	378	3.0 × 10 <sup>-4</sup>	(49)
C <sub>9</sub> H <sub>8</sub> O <sub>5</sub>	1-Monomethyl 4-hydroxyphthalate.....	25	0.01-0.0007	377	1.52 × 10 <sup>-4</sup>	(601)
C <sub>9</sub> H <sub>8</sub> O <sub>5</sub>	2-Monomethyl 4-hydroxyphthalate.....	25	0.016-0.001	377	2.02 × 10 <sup>-4</sup>	(598)
C <sub>9</sub> H <sub>8</sub> O <sub>5</sub>	1-Monomethyl 2-hydroxyterephthalate.....	25	0.001-0.0005	377	2.50 × 10 <sup>-4</sup>	(598)
C <sub>9</sub> H <sub>8</sub> O <sub>5</sub>	4-Monomethyl 2-hydroxyterephthalate.....	25	0.004-0.001	377	2.7 × 10 <sup>-5</sup>	(598)
C <sub>9</sub> H <sub>8</sub> O <sub>5</sub>	4-Methoxyisophthalic acid.....	25	0.002-0.0005	378	2.6 × 10 <sup>-4</sup>	(457)
C <sub>9</sub> H <sub>8</sub> O <sub>5</sub>	Carboxydehydroacetic acid.....	25	0.006-0.0016	376	$\Delta_{0.006} = 320$	(444)
C <sub>9</sub> H <sub>8</sub> BrO <sub>2</sub>	$\beta$ -Phenyl- $\alpha$ -bromopropionic acid.....	25	0.01-0.0005	378	1.67 × 10 <sup>-3</sup>	(514)
C <sub>9</sub> H <sub>8</sub> ClO <sub>2</sub>	$\alpha$ -Chloro- $\beta$ -hydroxyphenylpropionic acid.....	25	0.06-0.001	376	2.40 × 10 <sup>-3</sup>	(523)
C <sub>9</sub> H <sub>8</sub> ClO <sub>2</sub>	2-Ethoxy-5-chlorobenzoic acid.....	25	0.0011-0.0003	376	1.31 × 10 <sup>-4</sup>	(135)
C <sub>9</sub> H <sub>8</sub> ClO <sub>2</sub>	Ethyl 2-chlorogallate.....	25	0.04-0.005	375	1.8 × 10 <sup>-7</sup>	(135)
C <sub>9</sub> H <sub>8</sub> NO <sub>2</sub>	<i>o</i> -Acetylaminobenzoic acid.....	25	0.008-0.001	376	2.31 × 10 <sup>-4</sup>	(436)
C <sub>9</sub> H <sub>8</sub> NO <sub>2</sub>	<i>m</i> -Acetylaminobenzoic acid.....	25	0.004-0.001	376	8.4 × 10 <sup>-5</sup>	(436)
C <sub>9</sub> H <sub>8</sub> NO <sub>2</sub>	<i>p</i> -Acetylaminobenzoic acid.....	25	0.004-0.001	376	5.07 × 10 <sup>-5</sup>	(436)
C <sub>9</sub> H <sub>8</sub> NO <sub>2</sub>	Benzoylaminoacetic acid.....	25	0.03-0.001	376	2.16 × 10 <sup>-4</sup>	(378, 436, 622)
		0-65	0.008-0.0005			(525, 609)
C <sub>9</sub> H <sub>8</sub> NO <sub>2</sub>	1-Homophthalamic acid.....	25	0.002-0.001	378	5.0 × 10 <sup>-5</sup>	(540)
C <sub>9</sub> H <sub>8</sub> NO <sub>2</sub>	2-Homophthalamic acid.....	25	0.004-0.001	378	8.7 × 10 <sup>-5</sup>	(540)
C <sub>9</sub> H <sub>8</sub> NO <sub>2</sub>	Malonanilic acid.....	25	0.016-0.001	376	1.92 × 10 <sup>-4</sup>	(436)
C <sub>9</sub> H <sub>8</sub> NO <sub>2</sub>	$\alpha$ -Oximino- $\beta$ -phenylpropionic acid.....	25	0.03-0.004	377	5.9 × 10 <sup>-4</sup>	(265)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k (or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>9</sub> H <sub>9</sub> NO <sub>3</sub>	<i>p</i> -Tolyloxamic acid.....	25	0.008–0.001	376	8.3 × 10 <sup>-3</sup>	(436)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	1-Monomethyl 2-aminoterephthalate.....	25	0.001–0.0005	377	1.5 × 10 <sup>-4</sup>	(601)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	4-Monomethyl 2-aminoterephthalate.....	25	0.002–0.001	378	5.46 × 10 <sup>-5</sup>	(540)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	1-Monomethyl 4-aminoisophthalate.....	25	0.001–0.0005	377	4.4 × 10 <sup>-5</sup>	(601)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	3-Monomethyl 4-aminoisophthalate.....	25	0.001–0.0005	377	2.65 × 10 <sup>-5</sup>	(601)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	α, α'-Dimethylcinchomeric acid.....	25	0.012–0.0007	378	1.65 × 10 <sup>-3</sup>	(413)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	2, 4-Dimethylpyridine-3, 5-dicarboxylic acid.....	25	0.008–0.002	378	5.0 × 10 <sup>-3</sup>	(436)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	2, 6-Dimethylpyridine-3, 5-dicarboxylic acid.....	25	0.008–0.001	378	3.4 × 10 <sup>-3</sup>	(436)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	2- <i>N</i> -Methylaminoterephthalic acid.....	25	0.0016–0.0003	377	2.8 × 10 <sup>-4</sup>	(540, 601)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	Phenylglycine- <i>o</i> -carboxylic acid.....	25	0.007–0.0005	377	2.25 × 10 <sup>-4</sup>	(394)
C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	Monoethyl pyridine-3, 4-dicarboxylate.....	25	0.06–0.0008	378	4.8 × 10 <sup>-4</sup>	(49)
C <sub>9</sub> H <sub>9</sub> NO <sub>6</sub>	2-Nitro-3, 4-dimethoxybenzoic acid.....	25	0.0025–0.0006	376	7.9 × 10 <sup>-4</sup>	(323)
C <sub>9</sub> H <sub>9</sub> NO <sub>6</sub>	3-Nitro-2, 5-dimethoxybenzoic acid.....	25	0.0016–0.0008	376	1.7 × 10 <sup>-3</sup>	(323)
C <sub>9</sub> H <sub>9</sub> NO <sub>6</sub>	6-Nitro-2, 3-dimethoxybenzoic acid.....	25	0.01–0.0006	376	Λ <sub>0.01</sub> = 237.3	(323)
C <sub>9</sub> H <sub>9</sub> NO <sub>6</sub>	6-Nitroveratric acid.....	25	0.008–0.002	376	3.2 × 10 <sup>-3</sup>	(49)
C <sub>9</sub> H <sub>9</sub> N <sub>3</sub> OS	4-Methyl-1-phenyl-3-thiourazole.....	25	0.004–0.002	378	[Λ <sub>0.004</sub> = 319]	(6)
C <sub>9</sub> H <sub>9</sub> N <sub>3</sub> OS	1-Phenyl-3-methylthiourazole.....	25	0.001–0.00025	378	1.2 × 10 <sup>-7</sup>	(6)
C <sub>9</sub> H <sub>9</sub> N <sub>3</sub> O <sub>2</sub>	2-Methyl-1-phenylurazole.....	25	0.008–0.001	378	6.6 × 10 <sup>-8</sup>	(6)
C <sub>9</sub> H <sub>9</sub> N <sub>3</sub> O <sub>2</sub>	4-Methyl-1-phenylurazole.....	25	0.002–0.0005	378	1.2 × 10 <sup>-5</sup>	(6)
C <sub>9</sub> H <sub>10</sub> O <sub>2</sub>	2, 4-Dimethylbenzoic acid.....	25	0.001–0.0005	378	9 × 10 <sup>-5</sup>	(451)
C <sub>9</sub> H <sub>10</sub> O <sub>2</sub>	2, 5-Dimethylbenzoic acid.....	25	0.002–0.001	378	1.2 × 10 <sup>-4</sup>	(451)
C <sub>9</sub> H <sub>10</sub> O <sub>2</sub>	2, 6-Dimethylbenzoic acid.....	25	0.008–0.001	379	6.2 × 10 <sup>-4</sup>	(290)
C <sub>9</sub> H <sub>10</sub> O <sub>2</sub>	3, 5-Dimethylbenzoic acid.....	25	0.0012–0.0005	379	4.7 × 10 <sup>-5</sup>	(49)
					7.1 × 10 <sup>-5</sup>	(451)
C <sub>9</sub> H <sub>10</sub> O <sub>2</sub>	<i>o</i> -Ethylbenzoic acid.....	25	0.004–0.001	379	1.7 × 10 <sup>-4</sup>	(451)
C <sub>9</sub> H <sub>10</sub> O <sub>2</sub>	Hydratropic acid.....	25	0.016–0.001	378	4.16 × 10 <sup>-5</sup>	(436)
C <sub>9</sub> H <sub>10</sub> O <sub>2</sub>	Hydrocinnamic acid.....	25	0.016–0.001	378	2.23 × 10 <sup>-5</sup>	(436)
		0–65	0.03–0.0005			(526)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	<i>o</i> -Ethoxybenzoic acid.....	25	0.008–0.002	378	7.0 × 10 <sup>-5</sup>	(457)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	<i>m</i> -Ethoxybenzoic acid.....	25	0.002–0.0002	378	9.0 × 10 <sup>-5</sup>	(457)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	<i>p</i> -Ethoxybenzoic acid.....	25	0.0005–0.0002	378	5.0 × 10 <sup>-5</sup>	(457)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	<i>p</i> -Hydrocoumaric acid.....	25	0.008–0.001	378	1.71 × 10 <sup>-5</sup>	(436)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	4-Methoxy- <i>m</i> -toluic acid.....	25	0.008–0.0005	378	6.65 × 10 <sup>-5</sup>	(457)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	6-Methoxy- <i>m</i> -toluic acid.....	25	0.0005–0.0002	378	3.4 × 10 <sup>-5</sup>	(457)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	5-Methoxy- <i>o</i> -toluic acid.....	25	0.0005–0.0002	378	5.2 × 10 <sup>-5</sup>	(457)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	3-Methoxy- <i>p</i> -toluic acid.....	25	0.004–0.0002	378	4.04 × 10 <sup>-5</sup>	(457)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	α-Phenoxypropionic acid.....	25	(?)	(?)	7.75 × 10 <sup>-4</sup>	(56)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	β-Phenoxypropionic acid.....	25	(?)	(?)	5.4 × 10 <sup>-5</sup>	(56)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	β-Phenyl-α-hydroxypropionic acid.....	25	0.12–0.001	378	1.85 × 10 <sup>-4</sup>	(10, 79, 195)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	β-Phenyl-β-hydroxypropionic acid.....	25	0.12–0.001	378	3.90 × 10 <sup>-5</sup>	(10, 79, 195)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	<i>l</i> -Phenylmethoxyacetic acid.....	25	0.03–0.001	378	7.4 × 10 <sup>-4</sup>	(195, 389)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	Phloretic acid.....	25	0.016–0.001	378	2.01 × 10 <sup>-5</sup>	(436)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	Tropic acid.....	25	0.03–0.001	378	7.7 × 10 <sup>-5</sup>	(378); cf. (436)
C <sub>9</sub> H <sub>10</sub> O <sub>3</sub>	<i>p</i> -Xylenecarboxylic acid.....	25	0.0016–0.0008	378	6.0 × 10 <sup>-4</sup>	(378)
C <sub>9</sub> H <sub>10</sub> O <sub>4</sub>	Dehydrodiacetyllevulinic acid.....	25	0.004–0.0005	377	6.7 × 10 <sup>-5</sup>	(381)
C <sub>9</sub> H <sub>10</sub> O <sub>4</sub>	β-Phenylglyceric acid (M. P., 141°).....	25	0.5–0.004	376	2.35 × 10 <sup>-4</sup>	(75)
C <sub>9</sub> H <sub>10</sub> O <sub>4</sub>	β-Phenylglyceric acid (M. P., 121°).....	25	0.5–0.004	376	2.54 × 10 <sup>-4</sup>	(75)
C <sub>9</sub> H <sub>10</sub> O <sub>4</sub>	Veratric acid.....	25	0.004–0.001	378	3.54 × 10 <sup>-5</sup>	(436)
C <sub>9</sub> H <sub>10</sub> O <sub>6</sub>	Ethyl gallate.....	25	0.03–0.004	376	9 × 10 <sup>-8</sup>	(135)
C <sub>9</sub> H <sub>11</sub> NO	Hydroxyhydrindamine.....	25	0.03–0.004	220	1.35 × 10 <sup>-6</sup>	(459)
C <sub>9</sub> H <sub>11</sub> NO <sub>2</sub>	α-Anilinopropionic acid.....	25	0.008–0.001	376	2.05 × 10 <sup>-5</sup>	(579)
C <sub>9</sub> H <sub>11</sub> NO <sub>2</sub>	β-Anilinopropionic acid.....	25	0.005–0.0012	376	3.8 × 10 <sup>-6</sup>	(579)
C <sub>9</sub> H <sub>11</sub> NO <sub>2</sub>	<i>o</i> -Dimethylaminobenzoic acid.....	25	0.125	378	Λ <sub>0.125</sub> = 0.065	(140)
C <sub>9</sub> H <sub>11</sub> NO <sub>2</sub>	<i>m</i> -Dimethylaminobenzoic acid.....	25	0.008–0.001	378	6 × 10 <sup>-6</sup>	(140)
C <sub>9</sub> H <sub>11</sub> NO <sub>2</sub>	<i>p</i> -Dimethylaminobenzoic acid.....	25	0.0004	377	8.5 × 10 <sup>-6</sup>	(297)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Lambda_0$	<i>k</i> (or $\Lambda_c$ )	Lit.
Formula	Name					
C <sub>9</sub> H <sub>11</sub> NO <sub>2</sub>	<i>dl</i> -Phenyl- $\alpha$ -aminopropionic acid	25	0.008–0.001	375	$\Lambda_{0.008} = 3.9$	(303); <i>cf</i> (44)
C <sub>9</sub> H <sub>11</sub> NO <sub>2</sub>	<i>o</i> -Tolylaminoacetic acid	25	0.005–0.0006	377	$5.8 \times 10^{-5}$	(579)
C <sub>9</sub> H <sub>11</sub> NO <sub>2</sub>	<i>p</i> -Tolylaminoacetic acid	25	0.005–0.0012	377	$1.5 \times 10^{-5}$	(579)
C <sub>9</sub> H <sub>11</sub> NO <sub>2</sub>	<i>p</i> -Hydroxyphenyl- $\alpha$ -amino-propionic acid	25	0.002–0.001	(?)	$\Lambda_{0.002} = 0.5$	(304)
C <sub>9</sub> H <sub>11</sub> NO <sub>4</sub> S	<i>o</i> -Toluenesulfoneaminoacetic acid	25	0.015–0.001	374	$2.77 \times 10^{-4}$	(358)
C <sub>9</sub> H <sub>11</sub> NO <sub>4</sub> S	<i>p</i> -Toluenesulfoneaminoacetic acid	25	0.012–0.0015	374	$3.40 \times 10^{-4}$	(358)
C <sub>9</sub> H <sub>12</sub> AsNO <sub>6</sub>	Methoxyacetarsanilic acid	25	0.016–0.001	370	$3.0 \times 10^{-4}$	(355)
C <sub>9</sub> H <sub>12</sub> N <sub>2</sub> O	<i>O</i> -Ethyl- <i>N</i> -phenylpseudourea	25	0.04–0.0012	224	$5.0 \times 10^{-7}$	(107)
C <sub>9</sub> H <sub>12</sub> N <sub>2</sub> O	Pseudocumenediazonium hydroxide	0	0.008–0.002	137	$\Lambda_{0.008} = 107$	(166)
C <sub>9</sub> H <sub>12</sub> O <sub>3</sub>	Phenoxymethylglycol	25	0.12–0.016	(?)	$\Lambda_{0.125} = 0.04$	(65)
C <sub>9</sub> H <sub>12</sub> O <sub>3</sub> S	2-Pseudocumene-5-sulfonic acid	25	0.03–0.001	(?)	$\Lambda_{0.03} = 340$	(434)
C <sub>9</sub> H <sub>12</sub> O <sub>4</sub>	Diallylmalonic acid	25	0.03–0.004	378	$7.3 \times 10^{-3}$	(577)
C <sub>9</sub> H <sub>13</sub> N	Dimethylbenzylamine	25	0.05–0.0017	227	$8.5 \times 10^{-6}$	(207)
C <sub>9</sub> H <sub>13</sub> NO <sub>2</sub>	Isobutyl cyanoacetate	25	0.002–0.001	378	$6.5 \times 10^{-4}$	(214)
C <sub>9</sub> H <sub>13</sub> NO <sub>2</sub>	Methyl cyanoisovalerylacetate	25	(?)	376	$7 \times 10^{-4}$	(215)
C <sub>9</sub> H <sub>14</sub> O <sub>2</sub>	<i>cis-trans</i> - <i>dl</i> -Campholytic acid	25	0.01–0.0013	377	$9.1 \times 10^{-6}$	(584)
C <sub>9</sub> H <sub>14</sub> O <sub>2</sub>	Isocampholytic acid	25	0.0012–0.0006	377	$8.5 \times 10^{-6}$	(585)
C <sub>9</sub> H <sub>14</sub> O <sub>2</sub>	<i>l</i> -Campholytic acid	25	0.006–0.0016	377	$8.0 \times 10^{-6}$	(424)
C <sub>9</sub> H <sub>14</sub> O <sub>2</sub>	Launonic acid	(?)	(?)	(?)	$9.8 \times 10^{-6}$	(424)
C <sub>9</sub> H <sub>14</sub> O <sub>2</sub>	$\Delta^1$ -Tetrahydro-2, 6-dimethylbenzoic acid	25	0.0013–0.0010	378	$1.36 \times 10^{-5}$	(423)
C <sub>9</sub> H <sub>14</sub> O <sub>2</sub>	$\Delta^3$ -Tetrahydro-2, 6-dimethylbenzoic acid	25	0.0013–0.0010	378	$4.25 \times 10^{-5}$	(290)
C <sub>9</sub> H <sub>14</sub> O <sub>3</sub>	Isooctic acid	25	0.004–0.002	376	$4.08 \times 10^{-5}$	(290)
C <sub>9</sub> H <sub>14</sub> O <sub>4</sub>	Allylpropylmalonic acid	25	0.03–0.002	378	$7.5 \times 10^{-5}$	(569)
C <sub>9</sub> H <sub>14</sub> O <sub>4</sub>	Allylisopropylmalonic acid	25	0.03–0.002	378	$9.0 \times 10^{-5}$	(270)
C <sub>9</sub> H <sub>14</sub> O <sub>4</sub>	<i>meso-sym</i> -Ethylallylsuccinic acid	25	0.06–0.002	376	$1.4 \times 10^{-2}$	(270)
C <sub>9</sub> H <sub>14</sub> O <sub>4</sub>	<i>p-sym</i> -Ethylallylsuccinic acid	25	0.03–0.001	376	$3.5 \times 10^{-4}$	(577)
C <sub>9</sub> H <sub>14</sub> O <sub>4</sub>	Cyclopentane-1, 1-diacetic acid	25	0.008–0.0005	(?)	$2.6 \times 10^{-4}$	(577)
C <sub>9</sub> H <sub>14</sub> O <sub>4</sub>	<i>sym</i> -Tetramethyl- $\beta$ -hydroxyglutaric acid lactone ( <i>a</i> acid)	25	0.03–0.002	377	$1.73 \times 10^{-4}$	(525.2)
C <sub>9</sub> H <sub>14</sub> O <sub>4</sub>	<i>sym</i> -Tetramethyl- $\beta$ -hydroxyglutaric acid lactone ( <i>b</i> acid)	25	0.01–0.001	377	$1.5 \times 10^{-3}$	(403)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	<i>l</i> -Camphoronic acid	25	0.03–0.0005	378	$1.3 \times 10^{-3}$	(403)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	$\alpha$ , $\alpha'$ -Dimethyl- $\beta$ -acetoxylglutaric acid	25	0.03–0.001	374	$1.72 \times 10^{-4}$	(436)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	$\alpha$ , $\delta$ -Dimethylbutane- $\alpha$ , $\beta$ , $\delta$ -tricarboxylic acid	25	0.03–0.001	374	$1.97 \times 10^{-4}$	(471, 550)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	$\alpha$ (?)-Monomethyl $\alpha$ , $\alpha$ -dimethyltricarballylate	25	0.012–0.0015	376	$1.58 \times 10^{-4}$	(263)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	$\beta$ (?)-Monomethyl $\alpha$ , $\alpha$ -dimethyltricarballylate	25	0.08–0.004	375	$1.8 \times 10^{-4}$	(98)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	Methylethylcarboxylglutaric acid	25	0.11–0.014	375	$8.6 \times 10^{-6}$	(98)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	Propyltricarballylic acid	25	0.03–0.004	375	$9.5 \times 10^{-3}$	(578)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	Isopropyltricarballylic acid	25	0.03–0.001	375	$3.0 \times 10^{-4}$	(578)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	Terpylonic acid	25	0.03–0.001	375	$4.25 \times 10^{-4}$	(578)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	$\alpha$ , $\alpha$ , $\gamma$ -Trimethyltricarballylic acid	25	0.03–0.001	378	$1.02 \times 10^{-4}$	(511)
C <sub>9</sub> H <sub>14</sub> O <sub>6</sub>	?, ?, ?-Trimethyltricarballylic acid	25	0.02–0.007	376	$1.4 \times 10^{-4}$	(154, 263)
C <sub>9</sub> H <sub>14</sub> O <sub>7</sub>	$\alpha$ -Hydroxycamphoronic acid	25	0.016–0.002	376	$2.50 \times 10^{-4}$	(154)
C <sub>9</sub> H <sub>14</sub> O <sub>7</sub>	$\beta$ -Hydroxycamphoronic acid	25	0.016–0.002	378	$3.14 \times 10^{-3}$	(436)
C <sub>9</sub> H <sub>15</sub> NO	Trimethylphenylammonium hydroxide	25	0.004	378	$6.2 \times 10^{-3}$	(436)
C <sub>9</sub> H <sub>15</sub> NO <sub>2</sub>	<i>o</i> -Trimethylaminophenol	25	0.004	(?)	$\Lambda_{0.004} = 190$	(246)
C <sub>9</sub> H <sub>15</sub> NO <sub>2</sub>	<i>m</i> -Trimethylaminophenol	25	0.03	(?)	$\Lambda_{0.03} = 1.8$	(236)
C <sub>9</sub> H <sub>15</sub> NO <sub>2</sub>	<i>p</i> -Trimethylaminophenol	25	0.03	(?)	$\Lambda_{0.03} = 2.3$	(236)
C <sub>9</sub> H <sub>15</sub> O <sub>2</sub>	Cyclohexanepropionic acid	25	0.03	(?)	$\Lambda_{0.03} = 2.8$	(236)
C <sub>9</sub> H <sub>15</sub> O <sub>2</sub>	1, 3-Dimethylcyclohexane-3-carboxylic acid	25	0.005–0.0007	378	$1.32 \times 10^{-5}$	(635)
C <sub>9</sub> H <sub>15</sub> O <sub>2</sub>	<i>cis</i> -1, 3-Dimethylcyclohexane-5-carboxylic acid	25	0.004–0.0009	378	$6.2 \times 10^{-5}$	(635)
C <sub>9</sub> H <sub>15</sub> O <sub>2</sub>		25	0.004–0.001	378	$1.05 \times 10^{-5}$	(635)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	<i>trans</i> -1, 3-Dimethylcyclohexane-5-carboxylic acid.....	25	0.003–0.0008	378	1.07 × 10 <sup>-5</sup>	(635)
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	Hexahydro-2, 6-dimethylbenzoic acid.....	25	0.0013–0.0010	378	1.28 × 10 <sup>-5</sup>	(290)
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	1-Methylcyclohexane-3-acetic acid.....	25	0.005–0.0006	378	1.56 × 10 <sup>-5</sup>	(635)
C <sub>8</sub> H <sub>16</sub> O <sub>3</sub>	<i>cis</i> -Hydroxydihydrocampholytic acid.....	25	0.012–0.003	377	3.6 × 10 <sup>-5</sup>	(424)
C <sub>8</sub> H <sub>16</sub> O <sub>3</sub>	<i>trans</i> -Hydroxydihydrocampholytic acid.....	25	0.013–0.003	377	8.1 × 10 <sup>-5</sup>	(424)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Azelaic acid.....	25	0.012–0.0007	376	2.88 × 10 <sup>-5</sup>	(49, 565); cf. (524)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>α-sym.</i> -Diethylglutaric acid.....	25	0.007–0.0005	377	5.4 × 10 <sup>-5</sup>	(20, 49, 451)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>β-sym.</i> -Diethylglutaric acid.....	25	0.01–0.0007	377	5.9 × 10 <sup>-5</sup>	(20, 451)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>β, β</i> -Diethylglutaric acid.....	25	0.03–0.001	(?)	3.4 × 10 <sup>-4</sup>	(525.2)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Monoethyl diethylmalonate.....	25	0.03–0.0009	375	2.30 × 10 <sup>-4</sup>	(582)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>anti-α, α'</i> -Dimethylpimelic acid...	25	(?)	(?)	3.43 × 10 <sup>-5</sup>	(317)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>para-α, α'</i> -Dimethylpimelic acid...	25	(?)	(?)	3.44 × 10 <sup>-5</sup>	(317)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>α, α</i> -Dimethyl- <i>α'</i> -isopropylsuccinic acid.....	25	0.015–0.002	375	1.57 × 10 <sup>-4</sup>	(97)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Dimethylpropylsuccinic acid.....	25	0.016–0.001	376	5.4 × 10 <sup>-4</sup>	(577)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Dipropylmalonic acid.....	25	0.016–0.001	376	1.06 × 10 <sup>-2</sup>	(390, 524, 535)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Ethylbutylmalonic acid.....	0–65	0.03–0.0005			(526)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Ethylisobutylmalonic acid.....	25	0.03–0.001	375	9.1 × 10 <sup>-3</sup>	(390)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Methylisoamylmalonic acid.....	25	0.03–0.001	375	1.5 × 10 <sup>-2</sup>	(390)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>cis-α, α'</i> -Methylisobutylsuccinic acid.....	25	0.03–0.004	375	1.84 × 10 <sup>-3</sup>	(390)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>trans-α, α'</i> -Methylisobutylsuccinic acid.....	25	0.01–0.0014	375	4.27 × 10 <sup>-4</sup>	(97)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>α-sym.</i> -Methylpropylglutaric acid.....	25	0.016–0.002	376	2.35 × 10 <sup>-4</sup>	(97)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>β-sym.</i> -Methylpropylglutaric acid.....	25	0.03–0.002	376	5.3 × 10 <sup>-5</sup>	(60)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	<i>α</i> -Propyladipic acid.....	24.4	0.03–0.0016	375	5.8 × 10 <sup>-5</sup>	(60)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Monomethyl tetramethylsuccinate.....	25	0.02–0.003	374	4.0 × 10 <sup>-5</sup>	(391)
C <sub>8</sub> H <sub>16</sub> O <sub>5</sub>	<i>sym.</i> -Tetramethyl- <i>β</i> -hydroxyglutaric acid.....	25	0.04–0.0006	376	1.22 × 10 <sup>-5</sup>	(100)
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	Pelargonic acid.....	25	0.0008–0.0004	377	1.32 × 10 <sup>-4</sup>	(402)
C <sub>8</sub> H <sub>16</sub> O <sub>3</sub>	Dimethyl- <i>β</i> -isobutylethylenelactic acid.....	25	0.03–0.002	375	1.1 × 10 <sup>-5</sup>	(200)
C <sub>8</sub> H <sub>21</sub> N	Tripropylamine.....	25	0.005–0.002	224	1.45 × 10 <sup>-5</sup>	(550)
C <sub>10</sub> H <sub>6</sub> NO <sub>10</sub>	Pyridinepentacarboxylic acid.....	25	0.004–0.0002	(?)	4.5 × 10 <sup>-4</sup>	(104)
C <sub>10</sub> H <sub>6</sub> N <sub>2</sub> O <sub>8</sub> S	2, 4-Dinitro-1-naphthol-7-sulfonic acid.....	18	0.01–0.0006	(?)	Λ <sub>0.004</sub> = 650	(436)
		25	0.01–0.0012	(?)	[Λ <sub>0.01</sub> = 416]	(324)
		90	0.01–0.0012	(?)	Λ <sub>0.01</sub> = 245	(445)
		25	0.014–0.0009	(?)	[Λ <sub>0.01</sub> = 754]	(324)
C <sub>10</sub> H <sub>4</sub> O <sub>8</sub>	Pyromellitic acid.....	25	0.016–0.001	380	Λ <sub>0.014</sub> = 260	(49)
C <sub>10</sub> H <sub>7</sub> NO <sub>2</sub>	Cinchoninic acid.....	25	0.002–0.001	376	1.25 × 10 <sup>-5</sup>	(436)
C <sub>10</sub> H <sub>7</sub> NO <sub>2</sub>	1-Nitroso-2-naphthol.....	25	0.002–0.001	376	2.5 × 10 <sup>-8</sup>	(557)
C <sub>10</sub> H <sub>7</sub> NO <sub>2</sub>	2-Nitroso-1-naphthol.....	25	0.002–0.001	376	2.5 × 10 <sup>-8</sup>	(557)
C <sub>10</sub> H <sub>7</sub> NO <sub>2</sub>	4-Nitroso-1-naphthol.....	25	0.001–0.0005	376	2.6 × 10 <sup>-7</sup>	(557)
C <sub>10</sub> H <sub>7</sub> NO <sub>2</sub>	Quinaldinic acid.....	25	0.008–0.001	380	1.2 × 10 <sup>-5</sup>	(436)
C <sub>10</sub> H <sub>7</sub> NO <sub>3</sub>	Phenylisoxazolecarboxylic acid....	25	0.005–0.0007	377	5.4 × 10 <sup>-3</sup>	(7)
C <sub>10</sub> H <sub>7</sub> NO <sub>4</sub>	<i>o</i> -Phthalylaminoacetic acid.....	25	0.016–0.001	377	9.8 × 10 <sup>-4</sup>	(436)
C <sub>10</sub> H <sub>7</sub> NO <sub>5</sub> S	1, 5-Nitronaphthalenesulfonic acid.....	25	(?)	(?)	[1.5 × 10 <sup>-1</sup> ]	(194)
C <sub>10</sub> H <sub>7</sub> NO <sub>5</sub> S	1, 6-Nitronaphthalenesulfonic acid.....	25	(?)	(?)	[1.0 × 10 <sup>-1</sup> ]	(194)
C <sub>10</sub> H <sub>7</sub> NO <sub>5</sub> S	1, 7-Nitronaphthalenesulfonic acid.....	25	(?)	(?)	[1.3 × 10 <sup>-1</sup> ]	(194)
C <sub>10</sub> H <sub>7</sub> NO <sub>5</sub> S	1, 8-Nitronaphthalenesulfonic acid.....	25	(?)	(?)	[9.4 × 10 <sup>-2</sup> ]	(194)
C <sub>10</sub> H <sub>7</sub> NO <sub>11</sub> S <sub>2</sub>	1, 3, 6, 8-Nitronaphthalenetrisulfonic acid.....	25	(?)	(?)	[5.5 × 10 <sup>-2</sup> ]	(194)
C <sub>10</sub> H <sub>8</sub> Cl <sub>2</sub> O <sub>4</sub>	Monoethyl 3, 6-dichlorophthalate.....	25	0.004–0.001	376	1.5 × 10 <sup>-2</sup>	(598)
C <sub>10</sub> H <sub>8</sub> O	<i>α</i> -Naphthol.....	25	0.002–0.001	379	[1 × 10 <sup>-8</sup> ]	(569)
C <sub>10</sub> H <sub>8</sub> O <sub>2</sub>	1, 2-Dihydroxynaphthalene.....	25	0.16–0.002	(?)	Λ <sub>0.16</sub> = 0.026	(68, 70)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Lambda_0$	<i>k</i> (or $\Lambda_c$ )	Lit.
Formula	Name					
$C_{10}H_8O_2$	2, 3-Dihydroxynaphthalene.....	25	0.005–0.001	(?)	$\Lambda_{0.005} = 0.12$	(70)
$C_{10}H_7O_3S$	$\alpha$ -Naphthalenesulfonic acid.....	25	0.03–0.001	(?)	$\Lambda_{0.03} = 339$	(434)
$C_{10}H_7O_3S$	$\beta$ -Naphthalenesulfonic acid.....	25	0.42–0.0005	378	$\Lambda_{0.04} = 354$	(312, 466, 603)
$C_{10}H_8O_4$	Benzalmalonic acid.....	25	0.03–0.001	378	$4.04 \times 10^{-3}$	(436)
$C_{10}H_8O_4$	Benzoylpyroracemic acid.....	25	0.0025–0.0003	379	$6 \times 10^{-3}$	(7)
$C_{10}H_8O_4$	<i>allo</i> -Piperonylacrylic acid.....	25	0.0025–0.0006	377	$1.04 \times 10^{-4}$	(488)
$C_{10}H_8O_4$	Piperonylacrylic acid.....	25	0.00013	377	$2.4 \times 10^{-5}$	(488)
$C_{10}H_8O_5$	Monomethyl phthalonate.....	25	0.01–0.001	378	$1.5 \times 10^{-4}$	(540)
$C_{10}H_8O_5$	1-Monomethyl trimellitate.....	25	0.016–0.001	377	$1.8 \times 10^{-3}$	(601)
$C_{10}H_8O_5$	2-Monomethyl trimellitate.....	25	0.016–0.001	377	$2.6 \times 10^{-3}$	(601)
$C_{10}H_8O_5$	4-Monomethyl trimellitate.....	25	0.016–0.001	377	$2.86 \times 10^{-3}$	(601)
$C_{10}H_7BrO_3$	Bromoopianic acid.....	25	0.002–0.001	377	$4.30 \times 10^{-5}$	(601)
$C_{10}H_7NO_2$	3-Methylindole-3-carboxylic acid..	25	0.002–0.0005	376	$4.6 \times 10^{-5}$	(7)
$C_{10}H_7NO_2$	<i>Pr</i> -2-Methylindole-2-carboxylic acid.....	25	0.001–0.0002	376	$1.2 \times 10^{-6}$	(7)
$C_{10}H_7NO_3S$	1-Naphthylamine-2-sulfonic acid..	25	0.016–0.0005	376	$2 \times 10^{-3}$	(165)
$C_{10}H_7NO_3S$	1-Naphthylamine-4-sulfonic acid..	25	0.001–0.0001	376	$\Lambda_{0.001} = 276$	(165)
		0–65	0.001–0.0005			(526)
$C_{10}H_7NO_3S$	1-Naphthylamine-5-sulfonic acid..	25	0.004–0.0005	377	$2.3 \times 10^{-4}$	(165)
$C_{10}H_7NO_3S$	1-Naphthylamine-6-sulfonic acid..	25	0.004–0.0001	377	$1.92 \times 10^{-4}$	(165)
$C_{10}H_7NO_3S$	1-Naphthylamine-7-sulfonic acid..	25	0.008–0.0005	377	$2.22 \times 10^{-4}$	(165)
$C_{10}H_7NO_3S$	1-Naphthylamine-8-sulfonic acid..	25	0.001–0.0001	377	$1.00 \times 10^{-5}$	(165)
$C_{10}H_7NO_3S$	2-Naphthylamine-5-sulfonic acid..	25	0.004–0.0002	377	$9.2 \times 10^{-5}$	(165)
$C_{10}H_7NO_3S$	2-Naphthylamine-6(?)sulfonic acid..	25	0.001–0.0001	377	$1.63 \times 10^{-4}$	(165)
$C_{10}H_7NO_3S$	2-Naphthylamine-7-sulfonic acid..	25	0.002–0.0002	377	$1.0 \times 10^{-4}$	(165)
$C_{10}H_7NO_3S$	2-Naphthylamine-8-sulfonic acid..	25	0.002–0.0002	377	$1.20 \times 10^{-4}$	(165)
$C_{10}H_7NO_4$	2-Acetylaminoterephthalic acid...	25	0.0016–0.0005	377	$\Lambda_{0.001} = 242.0$	(540, 601)
$C_{10}H_7NO_4$	4-Acetylaminoisophthalic acid....	25	0.0004	377	$7.9 \times 10^{-4}$	(600)
					$1.1 \times 10^{-3}$	(599)
$C_{10}H_7NO_6$	2, 4-Dimethylpyridinetricarboxylic acid.....	25	0.03–0.0002	(?)	$\Lambda_{0.01} = 319$	(320)
$C_{10}H_7NO_6$	1-Monoethyl 4-nitrophthalate....	25	0.01–0.0007	377	$3.02 \times 10^{-3}$	(601)
$C_{10}H_7NO_6$	2-Monomethyl 4-nitrophthalate....	25	0.01–0.0006	377	$5.1 \times 10^{-3}$	(601)
$C_{10}H_7NO_6S_2$	1-Naphthylamine-2, 5(?)disulfonic acid.....	25	0.016–0.0002	374	$\Lambda_{0.016} = 338$	(165)
$C_{10}H_7NO_6S_2$	1-Naphthylamine-4, 6-disulfonic acid.....	25	0.016–0.0001	374	$\Lambda_{0.016} = 210$	(165)
$C_{10}H_7NO_6S_2$	1-Naphthylamine-4, 7-disulfonic acid.....	25	0.03–0.0002	374	$\Lambda_{0.03} = 186$	(165)
$C_{10}H_7NO_6S_2$	2-Naphthylamine-4, 8-disulfonic acid.....	25	0.016–0.0005	374	$\Lambda_{0.016} = 120$	(165)
$C_{10}H_7NO_7$	Nitroopianic acid.....	25	0.004–0.001	377	$2.85 \times 10^{-5}$	(540)
$C_{10}H_7NO_8$	Nitrohemipinic acid.....	25	0.03–0.002	376	$2.1 \times 10^{-3}$	(540, 604)
$C_{10}H_7NO_8S_2$	1-Naphthylamine-2, 4, 7-trisulfonic acid.....	25	0.02–0.0006	374	$\Lambda_{0.02} = 181$	(165)
$C_{10}H_7NO_8S_2$	1-Naphthylamine-3, 6, 8-trisulfonic acid.....	25	0.01–0.0002	374	$\Lambda_{0.01} = 198$	(165)
$C_{10}H_7N_3O_2$	3-Methyl-1-phenyl-4-isonitroso-5-pyrazolone.....	25	0.004–0.001	376	$2.3 \times 10^{-6}$	(235)
$C_{10}H_7N_3O_3$	Methyl 1-phenyl-5-hydroxy-1, 2, 3-triazole-4-carboxylate.....	25	0.007–0.0009	375	$[1.6 \times 10^{-2}]$	(157)
		50	0.01–0.0013	499	$[1.3 \times 10^{-2}]$	(157)
$C_{10}H_{10}BrNO_2$	Acetylbromophenylaminoacetic acid.....	25	0.003–0.0008	378	$2.80 \times 10^{-4}$	(579)
$C_{10}H_{10}BrNO_2$	Bromoacetylphenylaminoacetic acid.....	25	0.005–0.0006	378	$3.3 \times 10^{-4}$	(579)
$C_{10}H_{10}ClNO_2$	Chloroacetylphenylaminoacetic acid.....	25	0.005–0.0006	379	$3.33 \times 10^{-4}$	(579)
$C_{10}H_{10}ClNO_2$	<i>o</i> -Chlorosuccinanilic acid.....	25	0.008–0.001	376	$2.04 \times 10^{-5}$	(436)
$C_{10}H_{10}ClNO_2$	<i>m</i> -Chlorosuccinanilic acid.....	25	0.008–0.001	376	$2.05 \times 10^{-5}$	(436)
$C_{10}H_{10}ClNO_2$	<i>p</i> -Chlorosuccinanilic acid.....	25	0.008–0.001	376	$2.05 \times 10^{-5}$	(436)
$C_{10}H_{10}O_3$	$\beta$ -Benzoylpropionic acid.....	25	0.016–0.001	377	$2.23 \times 10^{-5}$	(244)
$C_{10}H_{10}O_3$	Furyldihydroresorcinol.....	25	0.003–0.0004	377	$1.48 \times 10^{-5}$	(508)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>10</sub> H <sub>10</sub> O <sub>3</sub>	<i>allo-p</i> -Methoxycinnamic acid.....	25	0.01–0.0012	377	8.85 × 10 <sup>-6</sup>	(488)
C <sub>10</sub> H <sub>10</sub> O <sub>3</sub>	<i>p</i> -Methoxycinnamic acid.....	25	0.0004–0.0002	377	2.0 × 10 <sup>-5</sup>	(488)
C <sub>10</sub> H <sub>10</sub> O <sub>3</sub>	Methylcoumaric acid.....	25	0.0005–0.0004	377	1.98 × 10 <sup>-5</sup>	(488)
C <sub>10</sub> H <sub>10</sub> O <sub>3</sub>	Methylcoumarinic acid.....	25	0.004–0.001	377	5.15 × 10 <sup>-5</sup>	(488)
C <sub>10</sub> H <sub>10</sub> O <sub>4</sub>	Benzylmalonic acid.....	25	0.03–0.001	378	1.52 × 10 <sup>-3</sup>	(577)
		0–65	0.03–0.0005			(526)
C <sub>10</sub> H <sub>10</sub> O <sub>4</sub>	1-Monomethyl homophthalate....	25	0.002–0.001	378	4.29 × 10 <sup>-5</sup>	(540)
C <sub>10</sub> H <sub>10</sub> O <sub>4</sub>	2-Monomethyl homophthalate....	25	0.004–0.001	378	7.5 × 10 <sup>-5</sup>	(540)
C <sub>10</sub> H <sub>10</sub> O <sub>4</sub>	1-Monomethyl 2-methylterephthalate.....	25	0.002–0.001	377	1.56 × 10 <sup>-4</sup>	(601)
C <sub>10</sub> H <sub>10</sub> O <sub>4</sub>	4-Monomethyl 2-methylterephthalate.....	25	0.002–0.0005	377	5.5 × 10 <sup>-4</sup>	(601)
C <sub>10</sub> H <sub>10</sub> O <sub>4</sub>	<i>o</i> -Phenylenediacetic acid.....	25	0.015–0.0009	376	1.08 × 10 <sup>-4</sup>	(34)
C <sub>10</sub> H <sub>10</sub> O <sub>4</sub>	Phenylsuccinic acid.....	25	0.016–0.0005	376	1.58 × 10 <sup>-4</sup>	(450, 602)
C <sub>10</sub> H <sub>10</sub> O <sub>4</sub>	Monoethyl phthalate.....	25	0.008–0.0005	376	5.50 × 10 <sup>-4</sup>	(582)
C <sub>10</sub> H <sub>10</sub> O <sub>5</sub>	Benzyltartronic acid.....	25	0.014–0.0009	378	5.3 × 10 <sup>-3</sup>	(577)
C <sub>10</sub> H <sub>10</sub> O <sub>5</sub>	1-Monoethyl 4-hydroxyphthalate.....	25	0.004–0.001	377	7.2 × 10 <sup>-4</sup>	(601)
C <sub>10</sub> H <sub>10</sub> O <sub>5</sub>	2-Monoethyl 4-hydroxyphthalate.....	25	0.004–0.001	377	2.15 × 10 <sup>-4</sup>	(601)
C <sub>10</sub> H <sub>10</sub> O <sub>5</sub>	Dimethyl 4-hydroxyphthalate....	25	0.008–0.001	376	1 × 10 <sup>-7</sup>	(598)
C <sub>10</sub> H <sub>10</sub> O <sub>5</sub>	Opianic acid.....	25	0.008–0.001	378	8.64 × 10 <sup>-4</sup>	(436)
C <sub>10</sub> H <sub>10</sub> O <sub>6</sub>	Apiolic acid.....	25	0.0008	377	8.0 × 10 <sup>-5</sup>	(7)
C <sub>10</sub> H <sub>10</sub> O <sub>6</sub>	Hemipinic acid.....	25	0.06–0.001	376	1.10 × 10 <sup>-3</sup>	(318, 598)
C <sub>10</sub> H <sub>10</sub> O <sub>6</sub>	<i>m</i> -Hemipinic acid.....	25	0.016–0.0005	378	1.42 × 10 <sup>-3</sup>	(436)
C <sub>10</sub> H <sub>11</sub> NO	Methylquinolinium hydroxide....	25	0.03	(?)	Λ <sub>0.03</sub> = 208	(241)
C <sub>10</sub> H <sub>11</sub> NO	Methylisoquinolinium hydroxide..	25	0.03	(?)	Λ <sub>0.03</sub> = 207	(241)
C <sub>10</sub> H <sub>11</sub> NO <sub>3</sub>	Benzoylaminopropionic acid.....	25	0.008–0.001	376	1.92 × 10 <sup>-4</sup>	(200)
C <sub>10</sub> H <sub>11</sub> NO <sub>3</sub>	β-Benzoylpropionic acid oxime (stable).....	25	0.016–0.004	378	1.7 × 10 <sup>-5</sup>	(244)
C <sub>10</sub> H <sub>11</sub> NO <sub>3</sub>	Methylbenzoylaminoacetic acid..	25	0.016–0.001	376	4.95 × 10 <sup>-4</sup>	(200)
C <sub>10</sub> H <sub>11</sub> NO <sub>3</sub>	Phenaceturic acid.....	25	0.007–0.001	376	1.98 × 10 <sup>-4</sup>	(200)
C <sub>10</sub> H <sub>11</sub> NO <sub>3</sub>	Phenylacetylaminacetic acid.....	25	0.005–0.0006	378	2.58 × 10 <sup>-4</sup>	(579)
C <sub>10</sub> H <sub>11</sub> NO <sub>3</sub>	Succinanilic acid.....	25	0.016–0.001	376	1.99 × 10 <sup>-5</sup>	(436)
C <sub>10</sub> H <sub>11</sub> NO <sub>3</sub>	<i>o</i> -Toluric acid.....	25	0.004–0.001	376	1.89 × 10 <sup>-4</sup>	(200)
C <sub>10</sub> H <sub>11</sub> NO <sub>3</sub>	<i>m</i> -Toluric acid.....	25	0.004–0.0005	376	2.06 × 10 <sup>-4</sup>	(200)
C <sub>10</sub> H <sub>11</sub> NO <sub>3</sub>	<i>p</i> -Toluric acid.....	25	0.004–0.0005	376	1.96 × 10 <sup>-4</sup>	(200)
C <sub>10</sub> H <sub>11</sub> NO <sub>4</sub>	1-Monoethyl 4-aminoisophthalate..	25	0.001–0.0003	376	4.0 × 10 <sup>-5</sup>	(601)
C <sub>10</sub> H <sub>11</sub> NO <sub>4</sub>	Anisuric acid.....	25	0.0014–0.0004	376	1.59 × 10 <sup>-4</sup>	(200)
C <sub>10</sub> H <sub>11</sub> NO <sub>4</sub>	4-Dimethylaminisophthalic acid..	25	0.001–0.0005	376	2.63 × 10 <sup>-4</sup>	(601)
C <sub>10</sub> H <sub>11</sub> NO <sub>4</sub>	Dimethylaminoterephthalic acid..	25	0.002–0.0005	376	4.5 × 10 <sup>-4</sup>	(601)
C <sub>10</sub> H <sub>11</sub> NO <sub>4</sub>	4-Monomethyl 2-methylaminoterephthalate.....	25	0.001–0.0005	376	3.6 × 10 <sup>-5</sup>	(601)
C <sub>10</sub> H <sub>11</sub> NO <sub>4</sub>	3-Nitrocumic acid.....	25	0.0005–0.0002	375	2.1 × 10 <sup>-4</sup>	(49)
C <sub>10</sub> H <sub>11</sub> NO <sub>4</sub>	<i>eso</i> -Monomethyl phenylglycine- <i>o</i> -carboxylate.....	25	0.0012–0.0003	376	1.3 × 10 <sup>-4</sup>	(394)
C <sub>10</sub> H <sub>11</sub> NO <sub>4</sub>	<i>exo</i> -Monomethyl phenylglycine- <i>o</i> -carboxylate.....	25	0.003–0.0004	376	2.7 × 10 <sup>-5</sup>	(394)
C <sub>10</sub> H <sub>11</sub> NO <sub>4</sub>	Phenyliminodiacetic acid.....	25	0.005–0.0012	375	2.65 × 10 <sup>-3</sup>	(579)
C <sub>10</sub> H <sub>11</sub> NO <sub>5</sub>	1-Hemipinamic acid.....	25	0.016–0.001	376	3.9 × 10 <sup>-4</sup>	(393)
C <sub>10</sub> H <sub>11</sub> NO <sub>5</sub>	2-Hemipinamic acid.....	25	0.016–0.001	376	6.8 × 10 <sup>-5</sup>	(393)
C <sub>10</sub> H <sub>11</sub> NO <sub>6</sub> S	Benzenesulfoneaminosuccinic acid..	25	0.04–0.0006	374	7.01 × 10 <sup>-4</sup>	(358)
C <sub>10</sub> H <sub>11</sub> N <sub>2</sub> OS	1-Phenyl-3-ethylthiourazole.....	25	0.0005–0.0002	378	5 × 10 <sup>-7</sup>	(6)
C <sub>10</sub> H <sub>11</sub> N <sub>2</sub> O <sub>2</sub>	1-Phenyl-3-ethoxyurazole.....	25	0.001–0.0001	376	4 × 10 <sup>-8</sup>	(6)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Cumic acid.....	25	0.002–0.001	376	4.9 × 10 <sup>-5</sup>	(436)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	2, 3, 4-Trimethylbenzoic acid....	25	0.002–0.0005	376	3.3 × 10 <sup>-5</sup>	(105, 451)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	2, 4, 5-Trimethylbenzoic acid....	25	0.001–0.0005	376	9.5 × 10 <sup>-5</sup>	(451)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	2, 4, 6-Trimethylbenzoic acid....	25	0.008–0.001	377	3.7 × 10 <sup>-4</sup>	(105, 451)
C <sub>10</sub> H <sub>12</sub> O <sub>3</sub>	5-Isopropylsalicylic acid.....	25	0.0012–0.0006	376	7.2 × 10 <sup>-4</sup>	(378)
C <sub>10</sub> H <sub>12</sub> O <sub>3</sub>	3-Ethoxy- <i>p</i> -toluic acid.....	25	0.002–0.0005	376	3.4 × 10 <sup>-5</sup>	(457)
C <sub>10</sub> H <sub>12</sub> O <sub>3</sub>	α-Methyl-β-phenyl-β-hydroxypropionic acid.....	25	0.03–0.0008	375	3.42 × 10 <sup>-5</sup>	(550)
C <sub>10</sub> H <sub>12</sub> O <sub>3</sub>	Phenylethoxyacetic acid.....	25	0.05–0.0014	377	5.2 × 10 <sup>-4</sup>	(195)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Delta_0$	<i>k</i> (or $\Delta_c$ )	Lit.
Formula	Name					
C <sub>10</sub> H <sub>12</sub> O <sub>3</sub>	$\alpha$ -Phenoxybutyric acid.....	25	(?)	(?)	6.82 $\times 10^{-4}$	(57)
C <sub>10</sub> H <sub>12</sub> O <sub>3</sub>	$\alpha$ -Phenoxyisobutyric acid.....	25	(?)	(?)	4.34 $\times 10^{-4}$	(57)
C <sub>10</sub> H <sub>12</sub> O <sub>8</sub>	1, 1, 3, 3-Hexamethylenetetra-carboxylic acid.....	25	0.05-0.0015	373	1.3 $\times 10^{-3}$	(582)
C <sub>10</sub> H <sub>13</sub> NO <sub>2</sub>	$\alpha$ -Anilinobutyric acid.....	25	0.008-0.001	373	2.8 $\times 10^{-5}$	(579)
C <sub>10</sub> H <sub>13</sub> NO <sub>2</sub>	$\alpha$ -Anilinoisobutyric acid.....	25	0.005-0.0012	373	3.6 $\times 10^{-5}$	(579)
C <sub>10</sub> H <sub>13</sub> NO <sub>2</sub>	$\beta$ -Anilinoisobutyric acid.....	25	0.005-0.0012	373	1.0 $\times 10^{-6}$	(579)
C <sub>10</sub> H <sub>13</sub> NO <sub>2</sub>	$\alpha$ - <i>o</i> -Toluidinopropionic acid.....	25	0.005-0.0012	373	3.8 $\times 10^{-5}$	(579)
C <sub>10</sub> H <sub>13</sub> NO <sub>2</sub>	$\alpha$ - <i>p</i> -Toluidinopropionic acid.....	25	0.002-0.001	373	6.7 $\times 10^{-6}$	(579)
C <sub>10</sub> H <sub>13</sub> NO <sub>2</sub>	$\beta$ - <i>p</i> -Toluidinopropionic acid.....	25	0.005-0.0012	373	2.2 $\times 10^{-6}$	(579)
C <sub>10</sub> H <sub>13</sub> NO <sub>4</sub> S	<i>m</i> -Xylenesulfoneaminoacetic acid.....	25	0.014-0.002	373	2.65 $\times 10^{-4}$	(358)
C <sub>10</sub> H <sub>13</sub> N <sub>4</sub> O <sub>8</sub> P	Inosinic acid.....	25	0.07-0.0005	375	$\Delta_{0.07} = 122$	(220)
C <sub>10</sub> H <sub>14</sub> N <sub>2</sub>	Nicotine.....	25	0.03-0.001	(?)	$\Delta_{0.03} = 2.0$	(416)
C <sub>10</sub> H <sub>14</sub> O	Isobutylphenol.....	25	0.003-0.0008	379	2.6 $\times 10^{-7}$	(26)
C <sub>10</sub> H <sub>14</sub> O <sub>4</sub>	Diisopropylsuccinic acid.....	25	0.008-0.001	375	1.4 $\times 10^{-4}$	(152)
C <sub>10</sub> H <sub>14</sub> O <sub>4</sub>	Methyl dimethylhydroresorcyate.....	25	0.07-0.0006	375	4.76 $\times 10^{-5}$	(508)
C <sub>10</sub> H <sub>14</sub> O <sub>4</sub>	Ethyl methylhydroresorcyate.....	25	0.06-0.0008	375	3.63 $\times 10^{-5}$	(508)
C <sub>10</sub> H <sub>15</sub> BrO <sub>4</sub> S	<i>o</i> -Bromocamphorsulfonic acid.....	25	0.5-0.001	378	$\Delta_{0.033} = 351$	(580)
C <sub>10</sub> H <sub>15</sub> NO <sub>3</sub>	Isoamyl cyanoacetate.....	25	0.001-0.0005	376	5.5 $\times 10^{-4}$	(214)
C <sub>10</sub> H <sub>16</sub> Fe <sub>2</sub> O <sub>11</sub>	Diferripentaacetyl hydroxide.....	25	0.03-0.001	(?)	$\Delta_{0.03} = 9.3$	(478)
C <sub>10</sub> H <sub>16</sub> O <sub>2</sub>	Campholenic acid.....	18	0.003-0.0003	340	1.65 $\times 10^{-5}$	(594)
C <sub>10</sub> H <sub>16</sub> O <sub>2</sub>	Fencholenic acid.....	18	0.003-0.0003	340	1 $\times 10^{-5}$	(594)
C <sub>10</sub> H <sub>16</sub> O <sub>2</sub>	Pinonic acid.....	25	0.005-0.001	375	2.1 $\times 10^{-5}$	(487)
C <sub>10</sub> H <sub>16</sub> O <sub>2</sub>	$\alpha$ -Tanacetoneketocarboxylic acid.....	25	0.01-0.0025	375	1.1 $\times 10^{-5}$	(487)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>d</i> -Camphoric acid.....	25	0.016-0.0005	378	2.20 $\times 10^{-5}$	(436, 534, 570, 620)
		0-35	0.016-0.0005			(45, 48, 610, 620)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>l</i> -Camphoric acid.....	25	(?)	378	2.20 $\times 10^{-5}$	(570)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>dl</i> -Camphoric acid.....	25	(?)	378	2.20 $\times 10^{-5}$	(570)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>d</i> -Isocamphoric acid.....	25	(?)	378	1.70 $\times 10^{-5}$	(570)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>l</i> -Isocamphoric acid.....	25	0.014-0.0018	378	1.58 $\times 10^{-5}$	(593)
					1.70 $\times 10^{-5}$	(570)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>dl</i> -Isocamphoric acid.....	25	(?)	378	1.70 $\times 10^{-4}$	(570)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	Cyclohexane-1, 1-diacetic acid.....	25	0.004-0.001	(?)	3.37 $\times 10^{-4}$	(525.5)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>cis-d</i> -Isocamphoric acid.....	25	0.016-0.002	377	4.84 $\times 10^{-5}$	(499)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>cis-l</i> -Isocamphoric acid.....	25	0.016-0.002	377	4.84 $\times 10^{-5}$	(499)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>cis-dl</i> -Isocamphoric acid.....	25	0.008-0.002	377	4.82 $\times 10^{-5}$	(499)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>trans-d</i> -Isocamphoric acid.....	25	0.016-0.002	377	4.12 $\times 10^{-5}$	(499)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>trans-l</i> -Isocamphoric acid.....	25	0.016-0.002	377	4.13 $\times 10^{-5}$	(499)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	<i>trans-dl</i> -Isocamphoric acid.....	25	0.008-0.002	377	4.12 $\times 10^{-5}$	(499)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	$\alpha$ , $\alpha$ , $\alpha'$ , $\alpha'$ -Tetramethyldihydro-muconic acid.....	25	0.04-0.005	375	1.78 $\times 10^{-5}$	(92)
C <sub>10</sub> H <sub>16</sub> O <sub>6</sub>	Cineolic acid.....	25	0.06-0.001	375	1.15 $\times 10^{-4}$	(378)
C <sub>10</sub> H <sub>16</sub> O <sub>6</sub>	Propylmethylcarboxylglutaric acid.....	25	0.03-0.004	375	9.9 $\times 10^{-3}$	(578)
C <sub>10</sub> H <sub>16</sub> O <sub>6</sub>	$\alpha$ , $\alpha$ , $\gamma$ , $\gamma$ -Tetramethyltricarballic acid.....	25	0.03-0.001	375	9.6 $\times 10^{-5}$	(578)
					1.50 $\times 10^{-4}$	(263)
C <sub>10</sub> H <sub>16</sub> O <sub>6</sub>	<i>p</i> -Tetramethyltricarballic acid.....	25	0.016-0.001	375	1.09 $\times 10^{-4}$	(578)
C <sub>10</sub> H <sub>17</sub> NO <sub>3</sub>	$\alpha$ -Camphoramic acid.....	25	0.016-0.002	376	1.4 $\times 10^{-5}$	(393)
C <sub>10</sub> H <sub>17</sub> NO <sub>3</sub>	$\beta$ -Camphoramic acid.....	25	0.016-0.002	376	1.25 $\times 10^{-5}$	(393)
C <sub>10</sub> H <sub>17</sub> N <sub>3</sub> O <sub>6</sub>	Antipeptone ( $\alpha$ ).....	[25]	0.12-0.001	(?)	$\Delta_{0.06} = 18.0$	(420)
C <sub>10</sub> H <sub>18</sub> O <sub>2</sub>	Campholic acid.....	25	0.001-0.0005	378	4.3 $\times 10^{-5}$	(436)
C <sub>10</sub> H <sub>18</sub> O <sub>3</sub>	Oxymenthyllic acid.....	25	0.02-0.0007	377	2.06 $\times 10^{-5}$	(436)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	Dihydrocamphoric acid.....	[25]	(?)	(?)	4.15 $\times 10^{-5}$	(137)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	$\alpha$ -Dihydroxydihydrocampholenic acid.....	18	0.018-0.0002	340	2.43 $\times 10^{-5}$	(594)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	$\alpha$ , $\alpha$ -Dimethyl- $\alpha'$ -isobutylsuccinic acid.....	25	0.004-0.0005	375	4.30 $\times 10^{-4}$	(97)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	<i>cis-sym</i> -Diisopropylsuccinic acid.....	25	0.008-0.001	375	2.3 $\times 10^{-3}$	(96); cf. (20)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	<i>trans-sym</i> -Diisopropylsuccinic acid.....	25	0.004-0.0005	375	1.08 $\times 10^{-4}$	(96)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	<i>cis-sym</i> -Dipropylsuccinic acid.....	25	0.008-0.001	375	4.9 $\times 10^{-4}$	(96)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	<i>trans-sym</i> -Dipropylsuccinic acid.....	25	0.004-0.0005	375	2.4 $\times 10^{-4}$	(96)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		<i>t</i> , °C	<i>c</i> -Range	$\Lambda_0$	<i>k</i> (or $\Lambda_c$ )	Lit.
Formula	Name					
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	Ethylisoamylmalonic acid.....	25	0.03–0.001	375	$8.6 \times 10^{-3}$	(390)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	Heptylmalonic acid.....	25	0.005–0.0006	375	$9.8 \times 10^{-4}$	(524, 535)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	<i>cis</i> - $\alpha$ -Methyl- $\alpha'$ -isoamylsuccinic acid.....	25	0.02–0.0025	375	$3.85 \times 10^{-4}$	(97)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	<i>trans</i> - $\alpha$ -Methyl- $\alpha'$ -isoamylsuccinic acid.....	25	0.005–0.0007	375	$2.35 \times 10^{-4}$	(97)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	<i>cis</i> - $\alpha$ -Propyl- $\alpha'$ -isopropylsuccinic acid.....	25	0.008–0.001	376	$2.90 \times 10^{-4}$	(96)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	<i>trans</i> - $\alpha$ -Propyl- $\alpha'$ -isopropylsuccinic acid.....	25	0.004–0.0005	376	$1.45 \times 10^{-4}$	(96)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	Sebacic acid.....	25	0.004–0.0008	376	$2.70 \times 10^{-5}$	(138, 565); <i>cf.</i> (436, 524)
		0–35	0.002–0.0005			(525)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	Monoethyl suberate.....	25	0.014–0.0009	375	$1.46 \times 10^{-5}$	(582)
C <sub>10</sub> H <sub>20</sub> O <sub>3</sub>	$\alpha$ -Isopropyl- $\beta$ -isobutylhydracrylic acid.....	25	0.02–0.002	376	$1.9 \times 10^{-5}$	(461)
C <sub>10</sub> H <sub>20</sub> O <sub>8</sub>	Tetramethylglucose.....	25	0.5	(?)	$\Lambda_{0.5} = 0.087$	(71)
C <sub>10</sub> H <sub>23</sub> N	Diisoamylamine.....	25	0.005–0.002	222	$7.7 \times 10^{-4}$	(104)
C <sub>11</sub> H <sub>8</sub> N <sub>2</sub> O <sub>2</sub>	3, 2'-Dipyridyl-3'-carboxylic acid..	25	0.016–0.001	376	$1.8 \times 10^{-5}$	(436)
C <sub>11</sub> H <sub>8</sub> N <sub>2</sub> O <sub>2</sub> S	<i>N</i> -Cyano- $\alpha$ -naphthalenesulfamide..	25	0.0005–0.00025	376	$1.6 \times 10^{-5}$	(26)
C <sub>11</sub> H <sub>8</sub> N <sub>2</sub> O <sub>2</sub> S	<i>N</i> -Cyano- $\beta$ -naphthalenesulfamide..	25	0.0004–0.0002	376	$6.6 \times 10^{-5}$	(26)
C <sub>11</sub> H <sub>8</sub> O <sub>2</sub>	$\alpha$ -Naphthoic acid.....	25	0.0005	377	$2.0 \times 10^{-4}$	(49)
C <sub>11</sub> H <sub>8</sub> O <sub>2</sub>	$\beta$ -Naphthoic acid.....	25	0.0003–0.0001	377	$6.9 \times 10^{-5}$	(151); <i>cf.</i> (26, 49)
C <sub>11</sub> H <sub>9</sub> NO <sub>3</sub>	Quininic acid.....	25	0.004–0.001	377	$9.0 \times 10^{-6}$	(436)
C <sub>11</sub> H <sub>10</sub> BrN <sub>3</sub> O <sub>3</sub>	Ethyl 1- <i>p</i> -bromophenyl-5-hydroxy-1, 2, 3-triazole-4-carboxylate.....	25	0.007–0.0017	375	$1.5 \times 10^{-2}$	(158)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	$\Delta^1$ -Dihydro- $\alpha$ -naphthoic acid.....	25	0.003–0.0001	376	$7.9 \times 10^{-5}$	(49, 151, 302)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	$\Delta^1$ -Dihydro- $\beta$ -naphthoic acid.....	25	0.0005–0.0001	376	$2.9 \times 10^{-5}$	(151)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	$\Delta^2$ -Dihydro- $\alpha$ -naphthoic acid.....	25	0.012–0.0001	376	$1.16 \times 10^{-4}$	(49, 151, 302)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	$\Delta^2$ -Dihydro- $\beta$ -naphthoic acid.....	25	0.0006–0.0001	376	$2.9 \times 10^{-5}$	(26)
					$2.5 \times 10^{-5}$	(151)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	$\Delta^3$ -Dihydro- $\beta$ -naphthoic acid.....	25	0.004–0.0001	376	$5.05 \times 10^{-5}$	(26)
					$5.75 \times 10^{-5}$	(151)
C <sub>11</sub> H <sub>10</sub> O <sub>3</sub>	Phenyltetric acid.....	25	0.004–0.0009	376	$1.90 \times 10^{-4}$	(573)
C <sub>11</sub> H <sub>10</sub> O <sub>4</sub>	Acetylcoumaric acid.....	25	0.0007	376	$4.7 \times 10^{-5}$	(488)
C <sub>11</sub> H <sub>10</sub> O <sub>4</sub>	Acetylcoumarinic acid.....	25	0.006–0.001	376	$1.07 \times 10^{-4}$	(488)
C <sub>11</sub> H <sub>10</sub> O <sub>4</sub>	Phenylitaconic acid.....	25	0.008–0.001	376	$1.35 \times 10^{-4}$	(540)
C <sub>11</sub> H <sub>10</sub> O <sub>5</sub>	$\beta$ -Benzoylisosuccinic acid.....	25	0.016–0.001	376	$2.4 \times 10^{-3}$	(524)
C <sub>11</sub> H <sub>10</sub> O <sub>6</sub>	1, 2-Dimethyl trimellitate.....	25	0.008–0.001	376	$3.4 \times 10^{-4}$	(601)
C <sub>11</sub> H <sub>10</sub> O <sub>7</sub>	Apionylglyoxylic acid.....	25	0.01–0.0014	376	$3.2 \times 10^{-2}$	(7)
C <sub>11</sub> H <sub>11</sub> NO <sub>2</sub>	2-Methylindole-3-acetic acid.....	25	0.004–0.0005	375	$2.1 \times 10^{-5}$	(7)
C <sub>11</sub> H <sub>11</sub> NO <sub>3</sub>	1-Monomethyl 2-acetylaminoterephthalate.....	25	0.001–0.0005	376	$2.58 \times 10^{-4}$	(601)
C <sub>11</sub> H <sub>11</sub> NO <sub>3</sub>	4-Monomethyl 2-acetylaminoterephthalate.....	25	0.0014–0.0003	376	$7.1 \times 10^{-4}$	(540, 601)
C <sub>11</sub> H <sub>11</sub> NO <sub>3</sub>	1-Monomethyl 4-acetylaminoisophthalate.....	25	0.001–0.0005	376	$6.9 \times 10^{-4}$	(601)
C <sub>11</sub> H <sub>11</sub> NO <sub>4</sub>	4-Acetylmethylaminoisophthalic acid.....	25	0.004–0.0005	376	$\Lambda_{0.004} = 137$	(601)
C <sub>11</sub> H <sub>11</sub> NO <sub>4</sub>	<i>N</i> -Acetylmethylaminoterephthalic acid.....	25	0.006–0.0005	376	$1.4 \times 10^{-3}$	(601); <i>cf.</i> (540)
C <sub>11</sub> H <sub>11</sub> NO <sub>4</sub>	Acetylphenylglycine- $\alpha$ -carboxylic acid.....	25	0.02–0.0016	376	$1.03 \times 10^{-3}$	(394)
C <sub>11</sub> H <sub>11</sub> NO <sub>4</sub>	Benzoylaminosuccinic acid.....	25	0.016–0.004	376	$5.22 \times 10^{-4}$	(442)
C <sub>11</sub> H <sub>11</sub> NO <sub>4</sub>	Anilindiacetic- $\alpha$ -carboxylic acid..	25	0.014–0.0016	375	$3 \times 10^{-3}$	(394)
C <sub>11</sub> H <sub>11</sub> NO <sub>4</sub>	1-Monomethyl nitrohemipinate...	25	0.004–0.0005	377	$\Lambda_{0.004} = 300$	(604)
C <sub>11</sub> H <sub>11</sub> NO <sub>4</sub>	2-Monomethyl nitrohemipinate...	25	0.004–0.001	377	$\Lambda_{0.004} = 307$	(604)
C <sub>11</sub> H <sub>12</sub> N <sub>2</sub> O <sub>4</sub>	Benzylidenehydrazinodiacetic acid..	25	0.002–0.0002	(?)	$\Lambda_{0.002} = 200.5$	(29)
C <sub>11</sub> H <sub>12</sub> O <sub>3</sub>	<i>ar.</i> - $\alpha$ -Tetrahydronaphthoic acid...	25	0.009–0.0001	376	$4.38 \times 10^{-5}$	(49, 151)
C <sub>11</sub> H <sub>12</sub> O <sub>3</sub>	$\beta$ -Tetrahydronaphthoic acid.....	25	0.005–0.0006	376	$2.45 \times 10^{-5}$	(26, 151)
C <sub>11</sub> H <sub>12</sub> O <sub>3</sub>	Ethylcoumaric acid.....	25	0.0005	376	$2.0 \times 10^{-5}$	(488)
C <sub>11</sub> H <sub>12</sub> O <sub>3</sub>	Ethylcoumarinic acid.....	25	0.003–0.0009	376	$4.35 \times 10^{-6}$	(488)



## Cu-Zn.—(Cont'd)

$t$	$\rho_t$
15.0 % Zn	
1100	29.87
1200	30.43
20 % Zn	
1000	33.03
$D = 0.40$	
1200	33.83
1100	33.44
39.61 % Zn	
900	43.90
1000	42.36
53.84 % Zn	
850	48.10
$D = -2.32$	
1000	44.62
60.7 % Zn	
850	48.59
900	47.35
1000	45.53
66.0 % Zn	
850	47.87
$D = -2.35$	
1000	44.34
85.0 % Zn	
700	44.04
$D = -1.24$	
900	41.56
100 % Zn	
700	35.65
$D = +0.05$	
900	35.75

<b>Cu-Zn-Pb (204)</b>	
34.58 % Zn; 2.42 % Pb; tr. of Fe, Sn	
20	7
50	7.55
944	41.61
1000	41.20
1084	40.11

<b>Fe-C (24)</b>	
0 % C	
1550	133.3
$D = 4.8$	
1650	138.1
0.22 % C	
1500	136.6
$D = 4.2$	
1650	142.9
1.19 % C	
1450	150.1
$D = 2.8$	
1650	155.7
3.80 % C	
1200	148.2
$D = 2.2$	
1600	157.0

<b>Hg-K (187)</b>	
1.65 % K	
$t_s = 62$	
62	128.80
100	133.95
150	140.80

## Hg-K.—(Cont'd)

$t$	$\rho_t$
1.65 % K	
$t_s = 62$	
200	147.80
250	155.18
300	162.75
350	170.60
3.52 % K	
$t_m = 162$	
162	165.76
200	170.18
250	176.38
300	183.95
350	192.18
6.56 % K	
$t_m = 262$	
262	197.80
300	203.90
350	213.45
400	223.40
450	233.0
8.56 % K	
$t_s = 287$	
287	199.90
300	202.25
350	211.95
400	221.50
9.62 % K	
$t_s = 282$	
282	208.5
350	222
400	232
11.92 % K	
$t_s = 256$	
256	232.60
300	237.00
350	242.0
21.34 % K	
$t_s = 162$	
162	240.25
200	241.5
$D = 3.12$	
350	246.18
39.45 % K	
$t_s = 87$	
87	130.20
100	132.80
150	142.50
200	153.75
250	163.18
300	173.60
350	184.05
79.35 % K	
$t_s = 57$	
57	37.10
100	41.30
$D = 9.71$	
350	65.58
100 % K	
$t_s = 64$	
64	12.98
100	15.3
$D = 6.48$	
200	21.78

## Hg-Na

$t$	$\rho_t$
0.11 % Na (23)	
50	99.76
100	102.74
150	110.20
200	116.56
250	123.60
300	131.42
0.11 % Na (187)	
$t_s = -43$	
100	103.75
150	109.25
200	115.00
250	121.50
300	128.50
350	135.90
0.39 % Na	
$t_s = -32$	
50	100.30
100	105.95
150	111.65
200	117.50
250	123.90
300	130.90
350	138.60
0.95 % Na	
$t_s = +56$	
56	98.1
100	102.90
$D = 10.74$	
350	129.75
3.03 % Na	
$t_s = 250$	
250	110.70
$D = 8.60$	
400	123.60
4.85 % Na	
$t_s = 352$	
352	110.15
$D = 4.90$	
450	115.05
5.7 % Na	
$t_s = 360$	
360	122.0
400	123.8
450	126.2
7.44 % Na	
$t_s = 320$	
320	126.4
350	128.05
$D = 5.70$	
500	136.6
17.35 % Na	
$t_s = 112$	
112	122.9
200	127.0
$D = 5.33$	
350	135.0
32.0 % Na	
$t_s = 47$	
47	105.6
100	107.40
$D = 3.47$	
400	117.80

## Hg-Na.—(Cont'd)

$t$	$\rho_t$
58.7 % Na	
$t_s = 65$	
65	59.4
100	51.6
$D = 3.34$	
400	61.62
100 % Na	
$t_s = 98$	
98	19.75
100	9.8
$D = 3.78$	
200	13.58
<b>K-Hg; v. Hg-K</b>	
<b>K-Na (197)</b>	
4.75 % K	
$t_s = 42$	
42	20.82
50	21.48
100	24.33
150	27.50
200	30.95
14.2 % K	
$t_s = 17$	
17	32.40
50	34.38
100	37.40
150	40.70
200	44.40
26.7 % K	
$t_s = -12.5$	
-12.5	35.65
+50	39.00
$D = 5.76$	
200	47.65
42.5 % K	
$t_s = +6.5$	
6.5	35.75
50	38.18
$D = 5.55$	
150	43.73
200	46.21
62.6 % K	
$t_s = 30.0$	
30.0	28.75
50	29.73
$D = 4.98$	
200	37.20
87.14 % K	
$t_s = 71$	
71	17.25
100	18.46
$D = 4.19$	
200	22.65
93.34 % K	
$t_s = 82$	
82	13.05
100	13.8
$D = 4.22$	
200	18.02
<b>K-Rb; v. Table 2</b>	

## K-Tl (23)

$t$	$\rho_t$
7.82 % Tl	
$t_m = 110$	
110	21.30
150	26.40
200	30.36
$D = 10.0$	
350	45.40
<b>Na-Cd (23)</b>	
4.39 % Cd	
$t_m = 122$	
122	15.30
150	16.18
200	17.71
250	19.25
300	21.24
350	23.36
<b>Na-Hg, Na-K; v. Hg-Na, K-Na</b>	
<b>Na-Pb (23)</b>	
8.26 % Pb	
$t_m = 185$	
185	24.0
200	24.74
$D = 4.78$	
350	31.91
<b>Na-Sb (23)</b>	
0.51 % Sb	
$t_m = 104$	
104	10.24
150	12.04
$D = 4.03$	
350	20.10
<b>Na-Tl (23)</b>	
7.61 % Tl	
$t_m = 93$	
93	20.40
100	20.48
150	22.32
200	24.10
250	26.00
300	28.24
350	30.58
<b>Ni-Cu; v. Cu-Ni</b>	
<b>Pb-Bi (197)</b>	
0 % Bi	
$t_s = 327$	
327	94.6
400	98.0
$D = 4.62$	
1000	125.7
1.197 % Bi	
$t_s = 327$	
327	97.8
400	97.8
$D = 4.60$	
1000	125.4
<b>Pb-Cd (197)</b>	
0 % Cd	
$t_s = 327$	
327	94.6
400	98.0

## Pb-Cd.—(Cont'd)

$t$	$\rho_t$
0 % Cd	
$D = 4.60$	
800	116.4
1.44 % Cd	
$t_s = 313$	
313	93.2
400	97.1
$D = 4.50$	
800	115.1
2.9 % Cd	
$t_s = 300$	
300	92.0
400	96.5
$D = 4.45$	
800	114.3
<b>Pb-Cu; v. Cu-Pb</b>	
<b>Pb-K (23)</b>	
0.38 % K	
$t_m = 319$	
319	93.6
350	95.76
$D = 6.98$	
600	113.22
<b>Pb-Na (23)</b>	
0.11 % Na	
$t_m = 326$	
326	95.64
350	96.90
$D = 5.31$	
650	112.84
<b>Pb-Sb (197)</b>	
0 % Sb	
$t_s = 327$	
327	94.6
400	98.0
$D = 4.62$	
1000	125.7
0.76 % Sb	
$t_s = 315$	
315	94.1
400	97.9
$D = 4.56$	
1000	125.25
2.03 % Sb	
$t_s = 300$	
300	93.0
400	97.6
$D = 4.57$	
1000	125.00
18.39 % Sb	
$t_s = 253$	
253	96.9
400	102.6
$D = 3.95$	
1000	126.3



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>11</sub> H <sub>16</sub> O <sub>4</sub>	3-Methylcyclohexylidenesuccinic acid.....	[25]	(?)	(?)	2.08 × 10 <sup>-4</sup>	(531)
C <sub>11</sub> H <sub>16</sub> O <sub>8</sub>	2, 6-Dimethylpentane-2, 6-tetracarboxylic acid.....	25	0.06-0.004	373	3.7 × 10 <sup>-3</sup>	(582)
C <sub>11</sub> H <sub>17</sub> N	Diethylbenzylamine.....	25	0.008-0.002	222	3.0 × 10 <sup>-5</sup>	(207)
C <sub>11</sub> H <sub>17</sub> NO <sub>3</sub>	Methyl 2-hydroxytrimethylammoniumbenzoate.....	1.2	0.016	(?)	Λ <sub>0.016</sub> = 134	(140)
C <sub>11</sub> H <sub>18</sub> O <sub>4</sub>	Cycloheptane-1, 1-diacetic acid....	25	0.004-0.001	(?)	3.95 × 10 <sup>-4</sup>	(525.2)
C <sub>11</sub> H <sub>18</sub> O <sub>4</sub>	Mono- <i>allo</i> -methyl <i>d</i> -camphorate....	25	0.005-0.0012	376	1.06 × 10 <sup>-5</sup>	(583)
C <sub>11</sub> H <sub>18</sub> O <sub>4</sub>	Mono- <i>o</i> -methyl <i>d</i> -camphorate.....	25	0.009-0.001	376	7.78 × 10 <sup>-6</sup>	(583)
C <sub>11</sub> H <sub>18</sub> O <sub>6</sub>	<i>sym.</i> -Tetramethyl-β-acetoxylglutaric acid.....	25	0.03-0.0016	375	5.2 × 10 <sup>-5</sup>	(402)
C <sub>11</sub> H <sub>19</sub> N <sub>3</sub> O <sub>5</sub>	Antipeptone (β).....	[25]	0.12-0.002	(?)	Λ <sub>0.06</sub> = 14.1	(420)
C <sub>11</sub> H <sub>20</sub> O <sub>4</sub>	2, 6-Diethylpimelic acid.....	25	0.007-0.0008	373	3.40 × 10 <sup>-5</sup>	(582)
C <sub>11</sub> H <sub>20</sub> O <sub>4</sub>	β, β-Dipropylglutaric acid.....	25	0.002-0.0005	(?)	3.4 × 10 <sup>-4</sup>	(525.2)
C <sub>11</sub> H <sub>20</sub> O <sub>4</sub>	Monomethyl <i>cis-sym.</i> -diisopropylsuccinate.....	25	0.004-0.0005	374	1.15 × 10 <sup>-4</sup>	(96)
C <sub>11</sub> H <sub>20</sub> O <sub>4</sub>	Monomethyl <i>trans-sym.</i> -diisopropylsuccinate.....	25	0.003-0.0003	374	6.3 × 10 <sup>-5</sup>	(96)
C <sub>11</sub> H <sub>20</sub> O <sub>4</sub>	α, α-Dimethyl-α'-isoamylsuccinic acid.....	25	0.008-0.001	375	6.1 × 10 <sup>-4</sup>	(97)
C <sub>11</sub> H <sub>20</sub> O <sub>4</sub>	Octylmalonic acid.....	25	0.002-0.0003	375	9.2 × 10 <sup>-4</sup>	(524)
C <sub>11</sub> H <sub>22</sub> O <sub>3</sub>	α-Dimethyl-β-hydroxypelargonic acid.....	25	0.008-0.0005	374	1.8 × 10 <sup>-5</sup>	(550)
C <sub>11</sub> H <sub>22</sub> O <sub>6</sub>	Tetramethyl-α-methylglucoside....	25	0.5	(?)	Λ <sub>0.5</sub> = 0.014	(71)
C <sub>11</sub> H <sub>22</sub> O <sub>6</sub>	Tetramethyl-β-methylglucoside....	25	0.5	(?)	Λ <sub>0.5</sub> = 0.038	(71)
C <sub>12</sub> H <sub>6</sub> O <sub>12</sub>	Mellitic acid.....	25	0.014-0.0004	(?)	Λ <sub>0.014</sub> = 450	(49); cf. (45)
C <sub>12</sub> H <sub>8</sub> N <sub>2</sub> O <sub>4</sub>	3, 2'-Dipyridyl-2, 3'-dicarboxylic acid.....	25	0.008-0.0005	376	3.1 × 10 <sup>-4</sup>	(436)
C <sub>12</sub> H <sub>9</sub> NO <sub>2</sub>	3-Phenylpyridinecarboxylic acid....	25	0.008-0.001	376	4 × 10 <sup>-6</sup>	(436)
C <sub>12</sub> H <sub>9</sub> N <sub>3</sub> S	Thionine.....	25	0.004	(?)	Λ <sub>0.004</sub> > 17.7	(230)
C <sub>12</sub> H <sub>10</sub> N <sub>2</sub> O	<i>p</i> -Oxyazobenzene.....	25	0.0009	(?)	Λ <sub>0.0009</sub> = 1.1	(179)
C <sub>12</sub> H <sub>11</sub> IO	Diphenyliodonium hydroxide.....	25	0.03-0.004	(?)	Λ <sub>0.03</sub> = 198	(539)
C <sub>12</sub> H <sub>11</sub> NO <sub>2</sub>	α-Naphthylaminoacetic acid.....	25	0.001-0.0005	373	3.2 × 10 <sup>-5</sup>	(579)
C <sub>12</sub> H <sub>11</sub> NO <sub>2</sub>	β-Naphthylaminoacetic acid.....	25	0.002-0.001	373	5.5 × 10 <sup>-6</sup>	(579)
C <sub>12</sub> H <sub>12</sub> O <sub>2</sub>	Phenyldihydroresorcinol.....	25	0.002-0.0005	376	1.14 × 10 <sup>-5</sup>	(508)
C <sub>12</sub> H <sub>12</sub> O <sub>4</sub>	Benzylglutaconic acid.....	25	0.06-0.0009	377	1.50 × 10 <sup>-4</sup>	(577)
C <sub>12</sub> H <sub>12</sub> O <sub>4</sub>	γ-Methyl-γ-phenylitaconic acid....	25	0.016-0.001	376	1.97 × 10 <sup>-4</sup>	(529)
C <sub>12</sub> H <sub>12</sub> O <sub>4</sub>	γ-Methyl-γ-phenylisoitaconic acid	25	0.017-0.0005	376	2.31 × 10 <sup>-4</sup>	(524, 529)
C <sub>12</sub> H <sub>12</sub> O <sub>4</sub>	γ-Methylene-γ-phenylpyrotartaric acid.....	25	0.016-0.001	376	1.91 × 10 <sup>-4</sup>	(529)
C <sub>12</sub> H <sub>12</sub> O <sub>6</sub>	α-Keto-γ-phenyladipic acid.....	25	0.03-0.004	375	8.9 × 10 <sup>-3</sup>	(156)
C <sub>12</sub> H <sub>12</sub> O <sub>6</sub>	Benzylethenyltricarboxylic acid....	25	0.03-0.016	375	3.0 × 10 <sup>-2</sup>	(578)
C <sub>12</sub> H <sub>12</sub> O <sub>8</sub>	Diacetyldiketohexamethylenedicarboxylic acid.....	[25]	0.001-0.0005	(?)	Λ <sub>0.001</sub> = 343	(184)
C <sub>12</sub> H <sub>13</sub> NO <sub>5</sub>	α-Monomethyl benzoylamino succinate.....	25	0.03-0.002	376	1.85 × 10 <sup>-4</sup>	(442)
C <sub>12</sub> H <sub>13</sub> NO <sub>5</sub>	β-Monomethyl benzoylamino succinate.....	25	0.016-0.002	376	4.9 × 10 <sup>-4</sup>	(442)
C <sub>12</sub> H <sub>13</sub> NO <sub>6</sub>	α-Ethyl 2, 4-dimethylpyridinetri-carboxylate.....	25	0.03-0.0005	(?)	Λ <sub>0.03</sub> = 263.6	(320)
C <sub>12</sub> H <sub>13</sub> NO <sub>6</sub>	β-Ethyl 2, 4-dimethylpyridinetri-carboxylate.....	25	0.03-0.0005	(?)	Λ <sub>0.03</sub> = 277.9	(320)
C <sub>12</sub> H <sub>13</sub> N <sub>3</sub> O <sub>3</sub>	Ethyl 1- <i>p</i> -tolyl-5-hydroxy-1, 2, 3-triazole-4-carboxylate.....	25	0.006-0.0014	374	1.0 × 10 <sup>-2</sup>	(158)
C <sub>12</sub> H <sub>14</sub> O <sub>3</sub>	β-Phenyl-γ-acetylbutyric acid.....	25	0.03-0.0005	375	3.13 × 10 <sup>-5</sup>	(508)
C <sub>12</sub> H <sub>14</sub> O <sub>4</sub>	Ethylbenzylmalonic acid.....	25	0.03-0.004	376	1.4 × 10 <sup>-2</sup>	(577)
C <sub>12</sub> H <sub>14</sub> O <sub>4</sub>	<i>meso-sym.</i> -Methylbenzylsuccinic acid.....	25	0.03-0.002	376	2.42 × 10 <sup>-4</sup>	(577)
C <sub>12</sub> H <sub>14</sub> O <sub>4</sub>	<i>p-sym.</i> -Methylbenzylsuccinic acid....	25	0.03-0.002	376	2.14 × 10 <sup>-4</sup>	(577)
C <sub>12</sub> H <sub>14</sub> O <sub>6</sub>	1-Monoethyl hemipinate.....	25	0.005-0.0007	375	1.45 × 10 <sup>-4</sup>	(597)
C <sub>12</sub> H <sub>14</sub> O <sub>6</sub>	2-Monoethyl hemipinate.....	25	0.007-0.0009	375	1.0 × 10 <sup>-4</sup>	(597)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	$\Lambda_0$	k(or $\Lambda_c$ )	Lit.
Formula	Name					
C <sub>12</sub> H <sub>15</sub> NO <sub>3</sub>	$\alpha$ -Acetylanilinobutyric acid.....	25	0.003-0.008	371	$1.05 \times 10^{-4}$	(579)
C <sub>12</sub> H <sub>15</sub> NO <sub>3</sub>	$\beta$ -Acetylanilinoisobutyric acid.....	25	0.003-0.0009	371	$2.7 \times 10^{-5}$	(579)
C <sub>12</sub> H <sub>15</sub> NO <sub>3</sub>	$\alpha$ -Acetyl- <i>o</i> -toluidinopropionic acid.....	25	0.003-0.0008	371	$1.02 \times 10^{-4}$	(579)
C <sub>12</sub> H <sub>15</sub> NO <sub>3</sub>	$\alpha$ -Acetyl- <i>p</i> -toluidinopropionic acid.....	25	0.003-0.0008	371	$1.02 \times 10^{-4}$	(579)
C <sub>12</sub> H <sub>15</sub> NO <sub>4</sub>	Cotarnine.....	0	0.008-0.001	134	$\Lambda_{0.008} = 53.5$	(241)
		25	0.008-0.001	226	$\Lambda_{0.008} = 124$	(241)
C <sub>12</sub> H <sub>16</sub> O <sub>3</sub>	$\alpha$ -Isopropyl- $\beta$ -phenyl- $\beta$ -hydroxypropionic acid.....	25	0.03-0.0009	374	$5.60 \times 10^{-5}$	(550)
C <sub>12</sub> H <sub>20</sub> O <sub>4</sub>	Mono- <i>o</i> -ethyl <i>l</i> -isocamphorate.....	25	0.004-0.002	375	$6.4 \times 10^{-6}$	(593)
C <sub>12</sub> H <sub>20</sub> O <sub>6</sub>	$\alpha$ , $\gamma$ -Diisopropyltricarballic acid (M. P., 156°).....	25	0.01-0.0013	374	$1.62 \times 10^{-3}$	(98)
C <sub>12</sub> H <sub>20</sub> O <sub>6</sub>	$\alpha$ , $\gamma$ -Diisopropyltricarballic acid (M. P., 173°).....	25	0.006-0.0008	374	$1.92 \times 10^{-3}$	(98)
C <sub>12</sub> H <sub>21</sub> NO	Triethylphenylammonium hydroxide.....	25	0.06-0.004	228	$\Lambda_{0.06} = 192$	(433)
C <sub>12</sub> H <sub>22</sub> O <sub>4</sub>	<i>cis-sym.</i> -Diisobutylsuccinic acid.....	25	0.0015-0.0004	375	$5.5 \times 10^{-4}$	(97)
C <sub>12</sub> H <sub>22</sub> O <sub>4</sub>	<i>trans-sym.</i> -Diisobutylsuccinic acid.....	25	0.001-0.0002	375	$2.24 \times 10^{-4}$	(97)
C <sub>12</sub> H <sub>22</sub> O <sub>4</sub>	Monoethyl sebacate.....	25	0.002-0.0005	374	$1.42 \times 10^{-5}$	(582)
C <sub>12</sub> H <sub>22</sub> O <sub>4</sub>	Tetraethylsuccinic acid.....	25	0.0011	374	$4.4 \times 10^{-4}$	(592)
C <sub>12</sub> H <sub>22</sub> O <sub>11</sub>	Saccharose.....	25	2.0-0.02	(?)	$\Lambda_{0.05} = 0.030$	(71, 210)
C <sub>12</sub> H <sub>27</sub> N	Triisobutylamine.....	25	0.002-0.001	220	$2.1 \times 10^{-4}$	(104)
C <sub>13</sub> H <sub>9</sub> N	Acridine.....	0	0.008	(?)	$\Lambda_{0.008} = 24$	(241)
C <sub>13</sub> H <sub>9</sub> NO <sub>4</sub>	$\alpha$ -Phenylpyridinedicarboxylic acid.....	25	0.008-0.0005	376	$1.2 \times 10^{-4}$	(436)
C <sub>13</sub> H <sub>9</sub> NO <sub>4</sub>	$\beta$ -Phenylpyridinedicarboxylic acid.....	25	0.016-0.0005	376	$1.08 \times 10^{-4}$	(436)
C <sub>13</sub> H <sub>11</sub> NO <sub>2</sub>	Phenyldihydroresorcylic acid nitrile.....	25	0.003-0.0003	376	$1.95 \times 10^{-4}$	(508)
C <sub>13</sub> H <sub>12</sub> O <sub>6</sub>	Mesitylenediglyoxylic acid.....	25	0.03-0.001	376	$\Lambda_{0.03} = 261$	(105)
C <sub>13</sub> H <sub>15</sub> NO <sub>5</sub>	<i>eso</i> -Monoethyl acetylphenylglycine- <i>o</i> -carboxylate.....	25	0.014-0.0009	374	$3.03 \times 10^{-4}$	(394)
C <sub>13</sub> H <sub>15</sub> NO <sub>5</sub>	<i>exo</i> -Monoethyl acetylphenylglycine- <i>o</i> -carboxylate.....	25	0.03-0.0016	374	$3.75 \times 10^{-4}$	(394)
C <sub>13</sub> H <sub>16</sub> O <sub>4</sub>	Dimethylbenzylsuccinic acid.....	25	0.016-0.002	376	$4.46 \times 10^{-4}$	(577)
C <sub>13</sub> H <sub>16</sub> O <sub>4</sub>	<i>meso</i> -Ethylbenzylsuccinic acid.....	25	0.03-0.002	376	$4.06 \times 10^{-4}$	(577)
C <sub>13</sub> H <sub>16</sub> O <sub>4</sub>	<i>para</i> -Ethylbenzylsuccinic acid.....	25	0.016-0.001	376	$2.57 \times 10^{-4}$	(577)
C <sub>13</sub> H <sub>16</sub> O <sub>4</sub>	Methylbenzylglutaric acid.....	25	0.03-0.002	376	$5.7 \times 10^{-5}$	(60)
C <sub>13</sub> H <sub>16</sub> O <sub>6</sub>	1-Monopropyl hemipinate.....	25	0.004-0.001	374	$9.2 \times 10^{-4}$	(598)
C <sub>13</sub> H <sub>16</sub> O <sub>6</sub>	2-Monopropyl hemipinate.....	25	0.002-0.001	374	$1.43 \times 10^{-4}$	(598)
C <sub>13</sub> H <sub>17</sub> NO <sub>3</sub>	$\alpha$ -Acetyl- <i>p</i> -toluidinobutyric acid.....	25	0.003-0.0008	371	$1.05 \times 10^{-4}$	(579)
C <sub>13</sub> H <sub>17</sub> NO <sub>3</sub>	$\alpha$ -Acetyl- <i>p</i> -toluidinoisobutyric acid.....	25	0.004-0.0009	371	$9.3 \times 10^{-5}$	(579)
C <sub>13</sub> H <sub>17</sub> NO <sub>3</sub>	$\beta$ -Acetyl- <i>p</i> -toluidinoisobutyric acid.....	25	0.003-0.0007	371	$2.24 \times 10^{-4}$	(579)
C <sub>13</sub> H <sub>17</sub> NO <sub>3</sub>	$\alpha$ -Acetyl- <i>o</i> -toluidinobutyric acid.....	25	0.004-0.001	371	$9.0 \times 10^{-5}$	(579)
C <sub>13</sub> H <sub>17</sub> NO <sub>3</sub>	$\beta$ -Acetyl- <i>o</i> -toluidinoisobutyric acid.....	25	0.002-0.001	371	$2.0 \times 10^{-5}$	(579)
C <sub>13</sub> H <sub>20</sub> O <sub>8</sub>	Diethylpentanetetracarboxylic acid.....	25	0.09-0.01	373	$2.1 \times 10^{-3}$	(582)
C <sub>13</sub> H <sub>24</sub> O <sub>4</sub>	2, 6-Dipropylpimelic acid.....	25	0.001-0.0002	373	$3.2 \times 10^{-5}$	(582)
C <sub>13</sub> H <sub>24</sub> O <sub>4</sub>	2, 6-Diisopropylpimelic acid.....	25	0.004-0.0005	373	$3.2 \times 10^{-5}$	(582)
C <sub>14</sub> H <sub>9</sub> BrO <sub>3</sub> S	10-Bromophenanthrene-3(or 6)-sulfonic acid.....	18	0.5-0.0002	(?)	$\Lambda_{0.05} = 220$	(503)
C <sub>14</sub> H <sub>10</sub> O <sub>3</sub>	Fluorene-9-hydroxy-9-carboxylic acid.....	25	0.01-0.0003	376	$1.18 \times 10^{-3}$	(67)
C <sub>14</sub> H <sub>10</sub> O <sub>3</sub>	<i>o</i> -Benzoylbenzoic acid.....	25	0.001-0.0002	376	$3.7 \times 10^{-4}$	(397)
C <sub>14</sub> H <sub>10</sub> O <sub>3</sub>	Diphenyleneglycolic acid.....	25	0.008-0.001	375	$9.8 \times 10^{-4}$	(358)
C <sub>14</sub> H <sub>10</sub> O <sub>3</sub> S	Phenanthrene-3-sulfonic acid.....	18	0.03-0.001	344	$\Lambda_{0.03} = 313$	(501)
C <sub>14</sub> H <sub>10</sub> O <sub>3</sub> S	Phenanthrene-10-sulfonic acid.....	18	0.03-0.001	344	$\Lambda_{0.03} = 319$	(502)
C <sub>14</sub> H <sub>10</sub> O <sub>4</sub>	Diphenic acid.....	25	0.008-0.0001	374	$5 \times 10^{-4}$	(432)
C <sub>14</sub> H <sub>10</sub> O <sub>6</sub>	$\alpha$ -Digallic acid.....	25	0.03-0.008	373	$1.1 \times 10^{-3}$	(571)
C <sub>14</sub> H <sub>11</sub> N	Methylacridine.....	0	0.004	(?)	$\Lambda_{0.004} = 55$	(241)
C <sub>14</sub> H <sub>12</sub> O <sub>2</sub>	Diphenylacetic acid.....	25	0.0004-0.0002	375	$1.1 \times 10^{-4}$	(558)
C <sub>14</sub> H <sub>12</sub> O <sub>3</sub>	Benzilic acid.....	25	0.02-0.0008	375	$9.0 \times 10^{-4}$	(49, 67, 378)
		0-65	0.008-0.0005			(610, 611)
C <sub>14</sub> H <sub>12</sub> O <sub>9</sub> (?)	Tannic acid.....	25	0.03-0.008	375	$\Lambda_{0.03} = 2.1$	(571)
C <sub>14</sub> H <sub>12</sub> NO <sub>2</sub>	Methylphenyldihydroresorcylic acid nitrile.....	25	0.004-0.0002	373	$2.0 \times 10^{-4}$	(508)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	Λ <sub>0</sub>	k(or Λ <sub>c</sub> )	Lit.
Formula	Name					
C <sub>14</sub> H <sub>13</sub> NO <sub>2</sub>	Acetyl-α-naphthylaminoacetic acid	25	0.004–0.0009	371	2.03 × 10 <sup>-4</sup>	(579)
C <sub>14</sub> H <sub>13</sub> NO <sub>2</sub>	Acetyl-β-naphthylaminoacetic acid	25	0.002–0.001	371	2.36 × 10 <sup>-4</sup>	(579)
C <sub>14</sub> H <sub>13</sub> NO <sub>4</sub>	α-Naphthyliminodiacetic acid.....	25	0.005–0.0012	371	5.0 × 10 <sup>-4</sup>	(579)
C <sub>14</sub> H <sub>13</sub> NO <sub>4</sub>	β-Naphthyliminodiacetic acid.....	25	0.005–0.0012	371	2.3 × 10 <sup>-3</sup>	(579)
C <sub>14</sub> H <sub>15</sub> NO <sub>7</sub>	Diethyl o-nitrobenzoylmalonate...	25	0.001–0.0004	371	2.10 × 10 <sup>-4</sup>	(569)
C <sub>14</sub> H <sub>15</sub> N <sub>2</sub> O <sub>8</sub> S	p-Dimethylaminoazobenzenesulfonic acid.....	25	0.001–0.0002	371	[3 × 10 <sup>-5</sup> ]	(622)
C <sub>14</sub> H <sub>16</sub> O <sub>6</sub>	Benzylisobutenyltricarboxylic acid	25	0.016–0.008	373	1.3 × 10 <sup>-2</sup>	(578)
C <sub>14</sub> H <sub>17</sub> NO <sub>6</sub>	α, β-Diethyl 2, 4-dimethylpyridine-tricarboxylate.....	25	0.016–0.001	371	1.8 × 10 <sup>-2</sup>	(320)
C <sub>14</sub> H <sub>18</sub> O <sub>2</sub>	dl-Amylcoumaric acid.....	25	0.0001	374	1.3 × 10 <sup>-5</sup>	(488)
C <sub>14</sub> H <sub>18</sub> O <sub>2</sub>	dl-Amylcoumarinic acid.....	25	0.0005	374	4.0 × 10 <sup>-5</sup>	(488)
C <sub>14</sub> H <sub>13</sub> NO <sub>4</sub>	Phenyllutidinedicarboxylic acid...	25	0.002–0.0005	376	1.15 × 10 <sup>-4</sup>	(436)
C <sub>14</sub> H <sub>13</sub> NO <sub>6</sub>	Pyropapaveric acid.....	25	0.0013–0.0003	376	Λ <sub>0.0013</sub> = 101.0	(49)
C <sub>14</sub> H <sub>14</sub> N <sub>2</sub> O <sub>6</sub>	Pyropapaveric acid ketoxime.....	25	0.0011–0.0006	376	3 × 10 <sup>-5</sup>	(49)
C <sub>14</sub> H <sub>16</sub> O <sub>4</sub>	Ethyl phenyldihydroresoreylate...	25	0.004–0.0004	375	6.05 × 10 <sup>-5</sup>	(508)
C <sub>14</sub> H <sub>20</sub> O <sub>2</sub>	β-Phenyl-γ-trimethylacetylbutyric acid.....	25	0.002–0.0003	375	2.5 × 10 <sup>-5</sup>	(508)
C <sub>16</sub> H <sub>11</sub> N <sub>2</sub> O <sub>4</sub>	Diphenylvioluric acid.....	[25]	(?)	(?)	7.7 × 10 <sup>-6</sup>	(348)
C <sub>16</sub> H <sub>13</sub> NO <sub>7</sub>	Papaveric acid.....	25	0.004–0.001	373	9 × 10 <sup>-3</sup>	(318, 436)
C <sub>16</sub> H <sub>13</sub> NO <sub>8</sub> S <sub>2</sub>	Phenyl-β-naphthylaminetrisulfonic acid.....	25	0.0013–0.00016	371	Λ <sub>0.0013</sub> = 351	(165)
C <sub>16</sub> H <sub>14</sub> N <sub>2</sub> O <sub>7</sub>	Papaveric acid ketoxime.....	25	0.002–0.0005	(?)	Λ <sub>0.002</sub> = 406	(49)
C <sub>16</sub> H <sub>14</sub> O <sub>2</sub>	Diphenylcrotonic acid.....	25	0.002–0.001	375	8 × 10 <sup>-5</sup>	(188, 338)
C <sub>16</sub> H <sub>14</sub> O <sub>2</sub>	β, γ-Diphenylvinylacetic acid.....	25	0.002–0.001	375	5.5 × 10 <sup>-4</sup>	(188, 338)
C <sub>16</sub> H <sub>14</sub> O <sub>4</sub>	β-para-Diphenylsuccinic acid.....	25	0.0005–0.0002	375	2.2 × 10 <sup>-4</sup>	(577)
C <sub>16</sub> H <sub>14</sub> O <sub>4</sub>	sym.-Diphenylsuccinic acid.....	25	0.02–0.0014	375	2.55 × 10 <sup>-4</sup>	(577)
C <sub>16</sub> H <sub>16</sub> NO <sub>4</sub>	Monomethyl phenyllutidinedicarboxylate.....	25	0.008–0.001	376	4.5 × 10 <sup>-5</sup>	(436)
C <sub>16</sub> H <sub>16</sub> O <sub>2</sub>	Dibenzylacetic acid.....	25	0.0005–0.0002	374	2.7 × 10 <sup>-5</sup>	(558)
C <sub>16</sub> H <sub>17</sub> NO <sub>2</sub>	Acetyl-β-naphthylaminoisobutyric acid.....	25	0.0012–0.0006	371	2.16 × 10 <sup>-5</sup>	(579)
C <sub>16</sub> H <sub>19</sub> N <sub>2</sub> OS	Tetramethylthionine hydroxide...	0	0.002	133	Λ <sub>0.002</sub> = 99	(230, 246)
		25	0.002	225	Λ <sub>0.002</sub> = 150	(230, 246)
C <sub>17</sub> H <sub>13</sub> O <sub>2</sub>	β-Chrysenic acid.....	25	0.0008–0.0003	375	9.0 × 10 <sup>-4</sup>	(601)
C <sub>17</sub> H <sub>15</sub> NO <sub>7</sub>	β-Monomethyl papaverate.....	25	0.002–0.001	375	4 × 10 <sup>-3</sup>	(598); cf. (318)
C <sub>17</sub> H <sub>15</sub> NO <sub>7</sub>	γ-Monomethyl papaverate.....	25	0.002–0.001	375	6 × 10 <sup>-3</sup>	(598); cf. (318)
C <sub>17</sub> H <sub>16</sub> O <sub>4</sub>	Dibenzylmalonic acid.....	25	0.008–0.004	374	3.8 × 10 <sup>-2</sup>	(577)
C <sub>17</sub> H <sub>16</sub> O <sub>4</sub>	Diphenylglutaric acid.....	25	0.003–0.0008	372	1.45 × 10 <sup>-4</sup>	(631)
C <sub>17</sub> H <sub>17</sub> N <sub>2</sub>	Anilopyrine.....	18	0.05–0.001	(?)	[Λ <sub>0.05</sub> = 80]	(401)
C <sub>17</sub> H <sub>19</sub> NO <sub>6</sub>	Morphine.....	18	0.0005	(?)	Λ <sub>0.0005</sub> = 9.5	(388)
		25	0.0006	(?)	Λ <sub>0.0006</sub> = 33	(392)
C <sub>17</sub> H <sub>21</sub> N <sub>2</sub>	Auramine G.....	0	0.001	(?)	Λ <sub>0.001</sub> = 30.6	(246, 626)
		25	0.001	(?)	Λ <sub>0.001</sub> = 48.3	(246, 626)
C <sub>17</sub> H <sub>21</sub> N <sub>2</sub>	Auramine O.....	0	0.001	(?)	Λ <sub>0.001</sub> = 30.8	(626)
		25	0.001	(?)	Λ <sub>0.001</sub> = 43.7	(626)
C <sub>17</sub> H <sub>23</sub> NO <sub>2</sub>	Atropine.....	25	0.005–0.0012	(?)	Λ <sub>0.005</sub> = 37	(587)
C <sub>17</sub> H <sub>23</sub> NO <sub>2</sub>	Hyoseyamine.....	25	0.01–0.0012	(?)	[Λ <sub>0.01</sub> = 19.3]	(587)
C <sub>18</sub> H <sub>17</sub> O <sub>4</sub>	Chrysodiphenic acid.....	25	0.0016–0.0004	375	1.6 × 10 <sup>-3</sup>	(601)
C <sub>18</sub> H <sub>14</sub> O <sub>6</sub>	Dibenzoyltartaric acid.....	25	0.003–0.0008	374	Λ <sub>0.0033</sub> = 257	(577)
C <sub>18</sub> H <sub>16</sub> N <sub>4</sub> O	Phenosafraanine.....	0	0.002	131	Λ <sub>0.002</sub> = 112	(246)
		25	0.002	222	Λ <sub>0.002</sub> = 176	(246)
C <sub>18</sub> H <sub>16</sub> O <sub>4</sub>	γ-Benzylidene-γ-phenylpyrotartaric acid.....	25	0.016–0.004	373	1.18 × 10 <sup>-4</sup>	(532)
C <sub>18</sub> H <sub>16</sub> O <sub>4</sub>	α-Truxillic acid.....	25	0.0002–0.0001	373	4.9 × 10 <sup>-5</sup>	(26)
C <sub>18</sub> H <sub>16</sub> O <sub>4</sub>	γ-Truxillic acid.....	25	0.002–0.0005	373	1.05 × 10 <sup>-4</sup>	(26)
C <sub>18</sub> H <sub>19</sub> N <sub>2</sub>	2, 5-Benzyliminopyrine.....	18	0.05–0.001	(?)	Λ <sub>0.05</sub> = 157	(401)
C <sub>18</sub> H <sub>23</sub> NO <sub>4</sub>	Methylmorphinium hydroxide.....	[25]	0.05	(?)	[Λ <sub>0.05</sub> = 5]	(219)
C <sub>18</sub> H <sub>19</sub> N <sub>2</sub> O	p-Triaminotriphenyl carbinol.....	0	0.002	(?)	Λ <sub>0.002</sub> > 85	(246)
		25	0.002	220	Λ <sub>0.002</sub> > 135	(246)
C <sub>19</sub> H <sub>23</sub> N <sub>2</sub> O	Cinchonine.....	18	0.00007	194	1.2 × 10 <sup>-6</sup>	(388)
C <sub>19</sub> H <sub>25</sub> O <sub>4</sub>	Cetylmalonic acid.....	25	0.004–0.0005	372	2.4 × 10 <sup>-7</sup>	(524)



C-Table.—The C-Arrangement.—(Continued)

Electrolyte		t, °C	c-Range	$\Delta_0$	k(or $\Delta_c$ )	Lit.
Formula	Name					
$C_{20}H_{14}N_2O_7S_2$	$\alpha$ -Naphthaleneazo- $\beta$ -naphtholdi-sulfonic acid.....	25	0.01–0.0006	(?)	$\Delta_{0.01} = 344$	(445)
$C_{20}H_{17}NO$	Methylphenylacridinium hydroxide.....	0	0.004	(?)	$[\Delta_{0.004} = 117]$	(241)
$C_{20}H_{21}NO_4$	Papaverine.....	18	0.00013	196	$2.8 \times 10^{-7}$	(388)
$C_{20}H_{24}N_2O_2$	Quinine.....	25	0.00016	222	$[5 \times 10^{-5}]$	(392)
		18	0.0006	196	$1.7 \times 10^{-6}$	(388)
		25	0.0007	222	$[1 \times 10^{-5}]$	(392)
$C_{21}H_{19}N_3O_4$	Pyropapaveric acid phenylhydrazone.....	25	0.001–0.0005	373	$3.6 \times 10^{-6}$	(49)
$C_{21}H_{22}N_2O_2$	Strychnine.....	18	0.0002	195	$8.5 \times 10^{-7}$	(388)
		25	0.0002	221	$[6 \times 10^{-5}]$	(392)
$C_{21}H_{24}O_4$	2, 6-Dibenzylpimelic acid.....	25	0.0005–0.0002	372	$4.8 \times 10^{-5}$	(582)
$C_{21}H_{34}N_6O_9$	Pepsin fibrin peptone ( $\alpha$ ).....	[25]	0.06–0.001	(?)	$\Delta_{0.06} = 10.8$	(420)
$C_{22}H_{16}ClN_2O$	6-Chloro- $\alpha$ -N-phenylnaphthophenazonium hydroxide.....	0	0.002	(?)	$\Delta_{0.002} > 110$	(246)
$C_{22}H_{16}N_3O$	Rosindulium hydroxide.....	25	0.002	225	$\Delta_{0.002} = 23.4$	(246)
$C_{22}H_{19}N_3O_6$	Papaveric acid phenylhydrazine.....	25	0.0005	373	$4.5 \times 10^{-3}$	(49)
$C_{22}H_{23}NO_7$	Narcotine.....	18	0.00004	(?)	$\Delta_{0.00004} = 8.5$	(388)
$C_{23}H_{20}O_6$	Methyl 3, 6-dimethoxyphenylxanthoniumcarboxylate.....	0	0.005	(?)	$\Delta_{0.005} = 82$	(307, 409)
$C_{23}H_{26}N_2O_4$	Brucine.....	18	0.0013	194	$1 \times 10^{-6}$	(388)
		25	0.0014–0.0007	220	$6 \times 10^{-6}$	(392)
$C_{25}H_{31}N_3O$	Hexamethyl-p-triaminotriphenyl carbinol (crystal violet).....	0	0.004–0.002	132	$\Delta_{0.004} = 110$	(246)
		25	0.004	223	$\Delta_{0.004} = 150$	(246)
$C_{26}H_{18}N_2O$	Phenylphenanthrophenazonium hydroxide.....	0	0.002	131	$\Delta_{0.002} > 3.4$	(246)
$C_{26}H_{43}NO_6$	Glycocholic acid.....	25	0.0013–0.0006	367	$1.3 \times 10^{-4}$	(91)
$C_{27}H_{34}N_2O$	Tetraethyldiaminotriphenyl carbinol (brilliant green).....	0	0.004	(?)	$\Delta_{0.004} = 24.3$	(246)
$C_{32}H_{24}N_6O_6S_2$	Congo blue.....	25	0.003–0.0004	(?)	$\Delta_{0.003} = 13.0$	(89)
$C_{32}H_{46}O_{16}$	Polymethacrylic acid.....	25	0.03–0.0005	367	$3.5 \times 10^{-8}$	(405)
$C_{37}H_{31}N_3O_{10}S_3$	Triphenyl-p-rosanilinetrisulfonic acid.....	18	0.0025–0.0006	(?)	$\Delta_{0.0025} = 556$	(324)
		90	0.0025–0.0006	(?)	$\Delta_{0.0025} = 1156$	(324)

## LITERATURE

(For a key to the periodicals see end of volume)

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- (10) Anschütz and Motschmann, 13, 392: 100; 12. (11) Arrhenius, 7, 4: 96; 89. (12) Arrhenius, 7, 5: 1; 90. (13) Aschan, 13, 271: 231; 92. (14) Askenasy and Meyer, 25, 26: 1354; 93. (15) Asriel, Diss., Heidelberg, 1900. (16) Auerbach, 7, 49: 217; 04. (17) Auerbach and Zeglin, 7, 103: 178; 23. (18) Auld and Hantzsch, 25, 38: 2677; 05. (19) Auwers, 13, 285: 241; 95.
- (20) Auwers, 13, 292: 132; 96. (21) Auwers, 13, 298: 147; 97. (22) Auwers and Campenhausen, 25, 29: 1543; 96. (23) Auwers and Jacob, 25, 27: 1114; 94. (24) Auwers, Köbner and Meyenburg, 25, 24: 2887; 91. (25) Auwers and Oswald, 13, 285: 283; 95. (26) Bader, 7, 5: 289; 90. (27) Baeyer, 13, 269: 145; 92. (28) Bailey and Mikeaka, 1, 38: 1771; 16.
- (29) Balbiano, 36, 29 II: 490; 99. (30) Bamberger, 25, 27: 359; 94. (31) Bamberger, 25, 35: 3697; 02. (32) Bamberger and Berlé, 13, 273: 303; 93. (33) Bamberger and Lodter, 13, 288: 74; 95. (34) Barmwater, 7, 45: 557; 03. (35) Barmwater, 7, 56: 225; 06. (36) Barth, 7, 9: 176; 92.
- (37) Baur, 13, 296: 95; 97. (38) Baur, 7, 18: 182; 95. (39) Baur, 7, 23: 409; 97. (40) Bayliss, 289, 36: 221; 08. (41) Berthelot, 6, 23: 5; 91. (42) Berthelot, 34, 112: 287; 91. (43) Berthelot, 34, 110: 703; 90. (44) Berthelot, 34, 112: 287; 91. (45) Bethmann, 7, 5: 385; 90.
- (46) Bichat, Bull. Soc. Nancy, (2) 11, Bull. des Séances, 7<sup>e</sup>, 16 (1891). (47) Billmann, 25, 43: 568; 10. (48) Billmann and Bjerrum, 25, 49: 2515; 16. (49) Billitzer, 57, 20: 666; 99. (50) Bischoff, 25, 24: 1064; 91. (51) Bischoff, 25, 24: 2001; 91. (52) Bischoff, 25, 33: 924; 00. (53) Bischoff, 25, 33: 931; 00. (54) Bischoff and Jaunack, 25, 23: 3399; 90. (55) Bischoff and Mintz, 25, 23: 3410; 90.
- (56) Bischoff and Walden, 25, 23: 1950; 90. (57) Bischoff and Walden, 25, 26: 1452; 93. (58) Bleekrode, 3, 5: 375; 78. (59) Bock, 8, 30: 631; 87. (60) Böseken and Couvert, 70, 29: 275; 10. (61) Böseken, 70, 34: 96; 15. (62) Böseken, Ruys and Brackmann, 70, 34: 272; 15. (63) Böseken, 70, 35: 211; 15. (64) Böseken, 70, 39: 178; 20. (65) Böseken and Felix, 70, 40: 568; 21.
- (66) Böseken, Anema and Brevet, 70, 41: 778; 22. (67) Böseken and Coops, 64V, 29: 368; 20. (68) Böseken and Couvert, 70, 40: 354; 21. (69) Böseken and Dujardin, 70, 32: 97; 13. (70) Böseken and van der Ent, 70, 37: 178; 18. (71) Böseken and van Giffen, 70, 39: 183; 20. (72) Böseken and de Graaff, 70, 41: 199; 22. (73) Böseken, Hansen and Bertram, 70, 35: 309; 16. (74) Böseken and Hermans, 70, 42: 1104; 23. (75) Böseken and van der Hoek Ostende, 70, 37: 162; 18. (76) Böseken and Kalshoven, 70, 37: 130; 18.
- (77) Böseken and van Lennep, 70, 31: 196; 12. (78) Böseken and Ouwehand, 70, 40: 574; 21. (79) Böseken and van Rossem, 70, 30: 392; 11. (80) Böseken and Rost van Tonnigen, 70, 39: 187; 20. (81) Böseken, Schweizer and van der Want, 70, 31: 86; 12. (82) Böseken, Sturm and Goettsch, 70, 37: 144; 18. (83) Böseken and Verkade, 70, 36: 167; 16. (84) Böseken and Voogd, 70, 42: 745; 23. (85) Böseken, Weisfelt, Spek, Loon and Goettsch, 70, 37: 165; 18. (86) Bogoiavlenski, 53, 44: 1813; 12.
- (87) Bollemont, 27, 25: 28; 01. (88) Bondi, 203, 53: 8; 07. (89) Bone and Henstock, 4, 83: 1380; 03. (90) Bone and Perkin, 4, 67: 108; 95. (91) Bone and Perkin, 4, 67: 416; 95. (92) Bone and Sprankling, 4, 75: 839; 99. (93) Bone and Sprankling, 4, 77: 654; 00. (94) Bone and Sprankling, 4, 77: 1298; 00. (95) Bone and Sprankling, 4, 81: 29; 02. (96) Bone and Sprankling, 4, 83: 1378; 03.
- (97) Bone, Sudborough and Sprankling, 4, 85: 534; 04. (98) Bouty, 8, 3: 161; 78. (99) Boyle, 4, 115: 1505; 19. (100) Bradley and Lewis, 50, 29: 782; 25. (101) Bredig, 7, 11: 829; 93. (102) Bredig, 7, 12: 289; 94. (103) Breed, Thesis, Bryn Mawr, 1901. (104) Bruce, 1, 26: 449; 04. (105) Bruner, 9, 19: 861; 13. (106) Bruni, 9, 14: 701; 08.



- (110) Bruni and Sandonnini, 9, 16: 223; 10. (111) Bruylanti and Stassens, 186, 1921: 702. (112) Buglia and Karczag, 22, 18 II: 374; 09. (113) Buglia and Karczag, 22, 18 II: 474; 09. (114) Bülow and Haas, 25, 43: 3401; 10. (115) Burke, 1, 42: 2500; 20. (116) Calcagni, 22, 25 I: 643; 16. (117) Caldwell, 5, 78A: 272; 06. (118) Carrara and Levi, 36, 32 II: 36; 02. (119) Carrara and Rossi, 36, 27 II: 505; 97.
- (120) Carré, 27, 33: 1314; 05. (121) Chanoz, *Ann. Univ. Lyon*, I, Fasc. 18: 1; 06. (122) Chavanne, 6, 3: 507; 04. (123) Chroustchoff, 34, 108: 1003; 89. (124) Claisen, 13, 297: 1; 97. (125) Clover and Jones, 11, 43: 187; 10. (127) Coffetti, 36, 30 II: 235; 00. (128) Collan, 7, 10: 130; 92. (129) Collie, 4, 77: 971; 00.
- (130) Collie and Hilditch, 4, 91: 787; 07. (131) Collie and Tickle, 4, 75: 710; 99. (132) Constam and White, 11, 29: 1; 03. (134) Coos, 25, 35: 4109; 02. (135) Coppadoro, 36, 32 I: 537; 02. (136) Creighton, 7, 81: 543; 12. (137) Crosaley and Perkin, 4, 73: 1; 98. (138) Crum Brown and Walker, 13, 261: 107; 91. (139) Crum Brown and Walker, 13, 274: 41; 93.
- (140) Cumming, 7, 57: 574; 06. (141) Dalle, 70, 21: 123; 02. (142) van Dam, 176, 7: 1013; 10. (143) Da Monte and Zoso, 36, 27 II: 467; 97. (144) Davidson and Hantzsch, 25, 31: 1612; 98. (145) Dawson and Crann, 4, 109: 1262; 16. (146) Dawson and Reiman, 4, 107: 1426; 15. (147) Deakin and Rivett, 4, 101: 127; 12. (148) Dedichen, 25, 39: 1831; 06. (149) Déguisne, *Diss.*, Strasbourg, 1895.
- (150) Derick and Hess, 1, 40: 537; 18. (151) Derick and Kamm, 1, 39: 388; 17. (152) Deschauer, *Diss.*, Heidelberg, 1905. (153) Deussen, 93, 44: 300; 05. (154) Devrient, *Diss.*, Leipzig, 1896. (155) Dieckmann, 25, 53: 1772; 20. (156) Dieckmann and Hardt, 25, 52: 1134; 19. (157) Dimroth, 13, 335: 1; 04. (158) Dimroth, 13, 338: 143; 05. (159) Dony-Hénault, 186, 1909: 342.
- (160) Doroshevskii and Rozhdestvenskii, 53, 40: 887; 08. (161) van Dorssen, 70, 29: 368; 10. (162) Drucker, 7, 49: 563; 04. (163) Drucker, 7, 52: 641; 05. (164) Drushel and Felty, 12, 43: 64; 17. (165) Ebersbach, 7, 11: 608; 93. (166) Engler and Hantzsch, 25, 33: 2147; 00. (167) Enklaar, 70, 24: 419; 05. (168) Erlenmeyer, 25, 42: 2649; 09. (169) Erlenmeyer, 25, 42: 2655; 09.
- (170) Esmann, *Diss.*, Leipzig, 1905. (171) Euler, 25, 39: 1607; 06. (172) Euler, 7, 21: 257; 96. (173) Euler and Bolin, 7, 66: 71; 09. (174) Euler and Euler, 19, 1: 111; 03. (175) Euler and Euler, 25, 36: 4253; 03. (176) Ewan, 4, 69: 96; 96. (177) Eykman, 25, 24: 1278; 91. (178) Fanjung, 7, 14: 673; 94. (179) Farmer and Hantzsch, 25, 32: 3089; 99.
- (180) Farmer and Hantzsch, 25, 32: 3101; 99. (181) Feist, 13, 267: 253; 90. (182) Feist, 25, 25: 315; 92. (183) Feist, 25, 26: 747; 93. (184) Feist, 25, 32: 315; 99. (185) Fichter, 25, 54: 1280; 21. (186) Fichter and Beiswenger, 25, 36: 1200; 03. (187) Fichter and Gisiger, 25, 42: 4707; 09. (188) Fichter and Latzko, 52, 74: 327; 06. (189) Fichter and Obladen, 25, 42: 4703; 09.
- (190) Fichter and Pfister, 13, 334: 201; 04. (191) Fichter and Probst, 13, 372: 69; 10. (192) Fichter and Schwab, 13, 348: 251; 06. (193) Fichter and Sonneborn, 25, 35: 938; 02. (194) Fierz-David and Wissenbach, 37, 3: 305; 20. (195) Findlay, Turner and Owen, 4, 95: 938; 09. (196) Fiorini, 36, 31 I: 33; 01. (197) Ford and Guthrie, 4, 89: 76; 06. (198) Foster, 2, 8: 257; 99.
- (200) Franke, 7, 16: 463; 95. (201) Frazer, 11, 30: 309; 03. (202) Freundlich and Krestovnikoff, 7, 76: 79; 11. (203) Gerilowski and Hantzsch, 25, 29: 743; 96. (204) Glimm, *Diss.*, Freiburg, 1902. (205) Gnehm and Sheutz, 52, 63: 405; 01. (206) Goldschmidt, 93, 28: 97; 01. (207) Goldschmidt and Salcher, 7, 29: 89; 99. (208) Gorke, 7, 61: 495; 08. (209) Graul and Hantzsch, 25, 31: 2854; 98.
- (210) Green, 4, 93: 2049; 08. (211) Grossmann and Krämer, 93, 41: 43; 04. (212) Gudzent, 7, 60: 25; 09. (213) Guinchant, 34, 120: 1220; 95. (214) Guinchant, 34, 121: 71; 95. (215) Guinchant, *Thesis*, Paris, 1897. 7, 24: 174; 97. (216) Guinchard, 25, 32: 1723; 99. (217) Guinchard, *Diss.*, Upsala, 1899. (218) Gutbier, 93, 29: 29; 04. (219) Hädrich, 7, 12: 476; 93.
- (220) Haiser and Wenzel, 57, 30: 377; 09. (220.1) Halban and Ebert, 7, 112: 359; 24. (221) Hallwachs, 8, 68: 1; 99. (222) Hantzsch, 13, 296: 84, 111; 97. (223) Hantzsch, 25, 22: 2827; 89. (224) Hantzsch, 25, 25: 827; 92. (225) Hantzsch, 25, 31: 607; 99. (226) Hantzsch, 25, 32: 3066; 99. (227) Hantzsch, 25, 35: 265; 02. (228) Hantzsch, 25, 36: 2069; 03. (229) Hantzsch, 25, 37: 1076; 04.
- (230) Hantzsch, 25, 38: 2143; 05. (231) Hantzsch, 25, 39: 139; 06. (232) Hantzsch, 25, 39: 3149; 06. (233) Hantzsch, 25, 40: 1523; 07. (234) Hantzsch, 25, 40: 1556; 07. (235) Hantzsch and Barth, 25, 35: 210; 02. (236) Hantzsch and Davidson, 25, 29: 1522; 96. (237) Hantzsch and Dollfus, 25, 35: 226; 02. (238) Hantzsch and Glover, 25, 40: 4344; 07. (239) Hantzsch and Holl, 25, 34: 3430; 01.
- (240) Hantzsch and Isberwood, 25, 42: 986; 09. (241) Hantzsch and Kalb, 25, 32: 3109; 99. (242) Hantzsch and Kaufmann, 13, 292: 317; 96. (243) Hantzsch and Lehmann, 25, 33: 3668; 00. (244) Hantzsch and Miolati, 7, 10: 1; 92. (245) Hantzsch and Osswald, 25, 32: 641; 99. (246) Hantzsch and Osswald, 25, 33: 278; 00. (247) Hantzsch and Rinckenberger, 25, 32: 628; 99. (248) Hantzsch and Robinson, 25, 43: 92; 10. (249) Hantzsch and Schultze, 25, 29: 2251; 96.
- (250) Hantzsch, Schumann and Engler, 25, 32: 1703; 99. (251) Hantzsch and Sebaldt, 7, 30: 258; 99. (252) Hantzsch and Sluiter, 25, 39: 162; 06. (253) Hantzsch and Vagt, 13, 314: 339; 01. (254) Hantzsch and Veit, 25, 32: 607; 99. (255) Hantzsch and Voegelen, 25, 34: 3142; 01. (256) Hantzsch and Voegelen, 25, 35: 1001; 02. (257) Hartley, Thomas and Applebey, 4, 93: 538; 08. (258) Heberlein, *Diss.*, Strasbourg, 1898. (259) Hedley, *Diss.*, Leipzig, 1908.
- (260) Henrich, 25, 37: 1406; 04. (261) Henrich, 57, 18: 142; 97. (262) Henry, 7, 10: 96; 92. (263) Henstock and Sprankling, 4, 91: 354; 07. (264) Henstock and Woolley, 4, 91: 1954; 07. (265) Hicks, 4, 113: 554; 18. (266) Hill and Sirkar, 5, 83A: 130; 10. (267) His and Paul, 7, 31: 1; 00. (268) Hjelt, 25, 25: 488; 92. (269) Hjelt, 25, 25: 524; 92.
- (270) Hjelt, 60, 38: 132; 95. (271) de Hlasko, 42, 20: 167; 23. (273) van't Hoff and Reicher, 7, 2: 777; 88. (274) Hofmann, Ehrhart and Schneider, 25, 46: 1657; 13. (275) Holleman, 70, 14: 121; 95. (276) Holleman, 70, 16: 162; 97. (277) Holleman, 70, 21: 56; 02. (278) Holleman, 70, 21: 432; 02. (279) Holleman and De Bruyn, 70, 20: 360; 01.
- (280) Holmberg and Mattisson, 13, 353: 123; 07. (281) Holmberg, 13, 353: 131; 07. (282) Holmberg, 13, 359: 81; 08. (283) Holmberg, 25, 45: 2997; 12. (284) Holmberg, 52, 71: 264; 05. (285) Holmberg, 52, 75: 169; 07. (286) Holmberg, 52, 79: 253; 09. (287) Hörcher, *Diss.*, Budapest, 1911. (288) van Hove, 186, 1909: 282. (289) Howles and Thorpe, 182, 15: 103; 99.
- (290) Hufferd and Noyes, 1, 43: 925; 21. (291) Inglis and Knight, 4, 93: 1595; 08. (292) Jacob, *Diss.*, Heidelberg, 1894. (293) Jahn, 7, 16: 72; 95. (294) James, 4, 103: 1368; 13. (295) Jellinek, 7, 76: 257; 11. (296) Johnston, 25, 37: 3625; 04. (297) Johnston, 7, 57: 557; 06. (298) Jones and Getman, 11, 32: 308; 04. (299) Jones and Jacobson, 11, 40: 355; 08.
- (300) Jones and West, 11, 34: 357; 05. (301) Joyner, 93, 77: 103; 12. (302) Kamm and McClugage, 1, 38: 419; 16. (303) Kanitz, 278, 118: 539; 07. (304) Kanitz, 202, 47: 476; 06. (305) Kanolt, 1, 29: 1402; 07. (307) Kehrmann, 13, 372: 287; 10. (308) Kendall, 1, 36: 1069; 14.
- (310) Kendall, 1, 38: 1480; 16. (311) Kendall, 1, 39: 7; 17. (312) Kendall, 4, 101: 1275; 12. (313) Kendall, 147, 2: No. 38; 13. (314) Kendall, 5, 85: 200; 11. (315) Kerp and Baur, 291, 26: 231; 07. (316) Kerp and Baur, 291, 26: 297; 07. (317) Kipping, 4, 67: 139; 95. (318) Kirpal, 57, 18: 461; 97. (319) Kirpal, 57, 28: 439; 07.
- (320) Kirpal and Reiman, 57, 38: 249; 17. (321) Klarmann, 93, 132: 289; 24. (322) Klasan and Carlson, 25, 39: 732; 06. (323) Klemenc and Müller, *Univ. Vienna*, 0. (324) Knecht and Batey, 290, 25: 194; 09. (325) Knox, 8, 54: 44; 95. (326) Kohlrausch, 8, 159: 233; 76. (327) Konowalow, 8, 49: 733; 93. (328) Kortright, 11, 18: 365; 96. (329) Kraemer, *Diss.*, Münster, 1904.
- (330) Kruyt, 64V, 22: 695; 14. (331) Kühling, 25, 38: 1638; 05. (332) Kuriloff, 7, 23: 90; 97. (333) Küster, 13, 315: 174; 01. (334) Küster, 13, 345: 1; 06. (335) Küster, 13, 346: 1; 06. (336) Küster, 25, 35: 1268; 02. (337) Küster, 25, 35: 2948; 02. (338) Latzko, *Diss.*, Basel, 1904. (339) Levi, 36, 31 II: 1; 01.
- (340) Ley, 25, 42: 354; 09. (341) Ley and Euler, 9, 13: 797; 07. (342) Ley and Hantzsch, 25, 39: 3149; 06. (343) Ley and Schaefer, 7, 42: 690; 03. (344) Lichty, 13, 319: 369; 01. (345) Liebermann, 25, 24: 1101; 91. (346) Liebermann, 25, 28: 129; 95. (347) Liebermann, 25, 36: 176; 03. (348) Lifschitz, 25, 46: 3233; 13. (349) Lindet, 34, 138: 508; 04.
- (350) Locke, 1, 46: 1246; 24. (351) Loomis, 8, 60: 523; 97. (352) Loomis, 8, 60: 547; 97. (353) Loomis, 2, 4: 252; 96. (354) Loomis, 2, 4: 273; 97. (355) Lorenz and Brehmer, 93, 128: 76; 23. (356) Lorenz and Schmidt, 93, 111: 175; 20. (357) Lovén, 7, 13: 550; 94. (358) Lovén, 7, 19: 456; 96. (359) Lovén and Ahlberg, 25, 54: 227; 21.
- (360) Lucas, 25, 32: 3179; 99. (361) Lumsden, 4, 87: 90; 05. (362) Lundén, 42, 5: 145; 07. (363) Lundén, 42, 5: 574; 07. (365) Lundén, 42, 8: 331; 10. (366) Lundén, 7, 54: 532; 06. (367) Lundén, 7, 70: 249; 10. (368) Luther, 9, 13: 294; 07. (369) Lutz, 25, 35: 2460; 02.
- (370) Lutz, 25, 35: 2549; 02. (371) Lutz, 25, 35: 4369; 02. (372) Maas, *Diss.*, München, 1909. (373) Mackay, 292, 11: 324; 06. (374) Magidson and Gorbachov, 25, 56: 1810; 23. (375) Magnanini, 36, 20: 453; 90. (376) Magnanini, 36, 21 II: 215; 91. (378) Magnanini, 36, 23 I: 197; 93. (379) Magnanini, 36, 26 II: 92; 96.
- (380) Magnanini, 7, 12: 56; 93. (381) Magnanini and Scheidt, 36, 22 I: 436; 92. (383) Maltby, 7, 18: 133; 95. (384) Mameli, 36, 41 I: 294; 11. (385) Manasse and Rupe, 25, 27: 1818; 94. (386) Marcilly, 27, 31: 119; 04. (387) Marquayrol and Carré, 27, 27: 199; 20. (388) Mauz, *Diss.*, Tübingen, 1904. (389) McKenzie, 4, 75: 753; 99.
- (390) Meldrum, 50, 15: 474; 11. (391) Mellor, 4, 79: 126; 01. (392) Mennicke, *Diss.*, Leipzig, 1897. (393) van der Meulen, *Diss.*, Basel, 1896. (394) Meusel, *Diss.*, Breslau, 1900. (395) Meyer, 25, 36: 3599; 03. (396) Meyer, 25, 44: 2966; 11. (397) Meyer, 57, 28: 1231; 07. (398) Meyer, 9, 13: 494; 07. (399) Meyer, 9, 17: 976; 11.
- (400) Michael and Bunge, 25, 41: 2907; 08. (401) Michaelis, 13, 339: 117; 05. (402) Michajlenko, 53, 30: 466; 98. (403) Michajlenko and Javorskii, 53, 32: 328; 00. (404) Miolati and Bellucci, 93, 26: 209; 01. (405) Mjöen, 25, 30: 1227; 97. (406) Moest, *Diss.*, Basel, 1899. (407) Moureu and Boutaric, 42, 18: 348; 20. (408) Mühlhauser, *Diss.*, Basel, 1902. (409) Müller, 25, 43: 2609; 10.



- (410) Muller, 27, 27: 1011; 02. (411) Muller and Bauer, 42, 2: 472; 04. (412) Mulliken, *Diss.*, Leipzig, 1890. (413) Mumm and Gottschaldt, 25, 55: 2064; 22. (414) Mündler, *Diss.*, Heidelberg, 1901. (415) Nasini and Costa, 22, 1891: 100. (416) Nasini and Pezzolato, 7, 12: 501; 93. (417) Naumann, 9, 16: 772; 10. (418) Neale, 83, 17: 505; 21. (419) Nernst and Hohmann, 7, 11: 352; 93.
- (420) Neumann, 202, 45: 216; 05. (421) Noyes, 1, 30: 335; 08. (422) Noyes, 7, 6: 241; 90. (423) Noyes and Burke, 1, 34: 174; 12. (424) Noyes and Potter, 1, 34: 1067; 12. (425) Noyes and Sammet, 7, 43: 513; 03. (426) Oliveri-Mandalà, 36, 40 I: 102; 10. (427) Oliveri-Mandalà, 36, 44 II: 175; 14. (428) Oliveri-Mandalà, 36, 45 I: 303; 15. (429) Oliveri-Mandalà, 36, 46 I: 298; 16.
- (430) Osaka, 7, 35: 661; 00. (431) Oslan, *Diss.*, Heidelberg, 1901. (432) Ostwald, 52, 32: 300; 85. (433) Ostwald, 52, 33: 352; 86. (434) Ostwald, 7, 1: 74; 87. (435) Ostwald, 7, 2: 270; 88. (436) Ostwald, 7, 3: 369; 89. (437) Ottén, *Diss.*, München, 1887. (438) Palomaa, 175, 3A: 1; 11. (439) Paul, 293, 239: 48; 01.
- (440) Paul, 7, 110: 417; 24. (441) Pauly, Schübel and Lockemann, 13, 383: 288; 11. (442) Pauly and Weir, 25, 43: 661; 10. (443) von Pechmann, 25, 33: 3323; 00. (444) von Pechmann and Neger, 13, 273: 186; 93. (445) Pelet-Jolivet and Wild, 27, 3: 1087; 08. (446) Peratoner and Palazzo, 36, 36 I: 7; 06. (447) Perkin, 4, 65: 572; 94. (448) Perkin, 4, 69: 1457; 96. (449) Perkin and Simonsen, 4, 91: 840; 07.
- (450) Petersen, 214, 7: 303; 90. (451) Pfaff, *Diss.*, Heidelberg, 1897. (452) Pfeiffer, 8, 23: 625; 84. (453) Philip, 4, 93: 925; 08. (454) Pick, 113, 374: 12. (455) Picton, *Diss.*, Leipzig, 1908. (456) Pilat, *Diss.*, Leipzig, 1905. (457) Pip, *Diss.*, Heidelberg, 1898. (458) Pomeranz, 57, 18: 575; 97. (459) Pope and Read, 4, 105: 811; 14.
- (460) Pospischill, 25, 31: 1950; 98. (461) Protopopov and Reformatskii, 53, 33: 242; 01. (462) Pummerer and Hofmann, 25, 56: 1255; 23. (463) Quinet, 51, 8: 278; 09. (464) Rabe, 25, 43: 2964; 10. (465) Ramberg, 25, 40: 2588; 07. (466) Ramstedt, 147, 3: No. 7; 15. (467) Ray, De and Dhar, 4, 103: 1562; 13. (468) Ray and Dey, 4, 111: 510; 17. (469) Ray, Dey and Ghosh, 4, 111: 413; 17.
- (470) Reformatskii, 25, 28: 3262; 95. (471) Reformatskii, 53, 30: 453; 98. (472) Rimbach and Neizert, 93, 52: 406; 07. (473) Rimbach and Weber, 7, 51: 473; 05. (474) Rivals, 6, 12: 501; 97. (475) Rivett and Sidgwick, 4, 97: 734; 10. (476) Rivett and Sidgwick, 4, 97: 1677; 10. (477) Robinson and Jones, 4, 101: 62; 12. (478) Rosenheim and Aron, 93, 39: 170; 04. (479) Rosenheim and Berthelm, 93, 34: 427; 03.
- (480) Rosenheim and Grünbaum, 93, 61: 187; 09. (481) Rosenheim and Pinsker, 25, 43: 2003; 10. (482) Rosenheim and Stadler, 25, 38: 2687; 05. (483) Rosenheim and Weinheber, 93, 69: 261; 11. (484) Rosenmund and Pfannkuch, 25, 55: 2357; 22. (485) Ross, 292, 11: 95; 02. (486) Roth, 25, 33: 2032; 00. (487) Roth and Östling, 25, 46: 309; 13. (488) Roth and Stoermer, 25, 46: 280; 13. (489) Rothmund and Drucker, 7, 46: 827; 03.
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- (530) Stobbe, 13, 321: 105; 02. (531) Stobbe, 52, 197: 329; 15. (532) Stobbe and Russwurm, 13, 308: 156; 99. (533) Stoddard, 11, 47: 1; 12. (534) Stohmann and Kleber, 52, 45: 475; 92. (535) Stohmann, Kleber, Langbein and Offenbauer, 52, 49: 99; 94. (536) Stohmann and Langbein, 52, 50: 388; 94. (537) Stohmann and Schmidt, 52, 53: 345; 96. (538) Strecker, 25, 43: 1131; 10. (539) Sullivan, 7, 28: 523; 99.
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- (580) Walden, 7, 15: 196; 94. (581) Walden, 7, 46: 103; 03. (582) Walker, 4, 61: 696; 92. (583) Walker, 4, 61: 1088; 92. (584) Walker, 4, 63: 495; 93. (585) Walker, 4, 67: 347; 95. (586) Walker, 7, 4: 319; 89. (587) Walker, 7, 51: 706; 05. (588) Walker and Cormack, 4, 77: 5; 00.
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- (600) Wegscheider, 57, 26: 1265; 05. (601) Wegscheider, 57, 37: 219; 16. (602) Wegscheider and Hecht, 57, 24: 413; 03. (603) Wegscheider and Lux, 57, 30: 411; 09. (604) Wegscheider and Müller, 57, 23: 899; 12. (605) Wegscheider and Rusnov, 57, 24: 375; 03. (606) West, 4, 77: 705; 00. (607) Whetham, 3, 44: 1; 97. (608) White and Jones, 11, 43: 520; 09. (609) White and Jones, 11, 44: 159; 10.
- (610) Wightman and Jones, 11, 46: 56; 11. (611) Wightman and Jones, 11, 48: 320; 12. (612) Wildermann, 7, 14: 247; 94. (613) Wilke, 93, 119: 365; 22. (614) Willstätter, 25, 28: 3271; 95. (615) Willstätter, 25, 31: 1534; 98. (616) Willstätter, 25, 32: 1635; 99. (617) Willstätter and Hollander, 13, 326: 79; 03. (618) Willstätter and Lessing, 25, 35: 2065; 02. (619) Wilsdon and Sidgwick, 4, 103: 1959; 13.
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- (630) Zelinakii, 25, 29: 616; 96. (631) Zelinakii, 53, 23: 612; 91. (632) Zelinakii and Bearedka, 25, 24: 459; 91. (633) Zelinakii and Generosow, 25, 29: 729; 96. (634) Zelinakii and Isajew, 25, 29: 819; 96. (635) Zelinakii and Isagariahev, 53, 40: 1379; 08. (636) Zinke, 13, 296: 135; 97. (637) Zinke and Greune, 13, 427: 221; 22.



## ELECTROLYTIC CONDUCTIVITY OF AQUEOUS SOLUTIONS CONTAINING TWO OR MORE SOLUTES

CLARENCE J. WEST

The following bibliography has been compiled chiefly from the data recorded in Annual Tables. The solutes are arranged in the Standard arrangement (*v.* Vol. III, p. viii), except that the organic components are all placed under the inorganic component with which they were studied.

The temperature of the observation and the literature citation follow the second component.

	$\text{H}_2\text{O}_2$
LiOH, 25° (32, 37)	
NaOH, 25° (32, 74)	
KOH, 25° (32, 37)	
$\text{K}_2\text{SO}_4$ (77)	
RbOH, 25° (32, 37)	
$\text{CsOH}$ , 25° (32, 37)	
	HF
$\text{H}_3\text{BO}_3$ , 25° (1)	
	HCl
$\text{HNO}_3$ , 18° (47.1)	
$\text{H}_3\text{AsO}_4$ , 25° (97, 113)	
$\text{BiCl}_3$ , 25° (85)	
$\text{H}_2\text{BiCl}_5$ , 25° (85)	
$\text{CH}_4\text{O}$ (Methyl alcohol), 25° (53)	
$\text{C}_2\text{H}_4\text{O}_2$ (Acetic acid), 18° (3)	
$\text{C}_2\text{H}_6\text{O}$ (Ethyl alcohol), 25° (57)	
$\text{C}_6\text{H}_8\text{O}_7$ (Citric acid), 18° (93)	
$\text{C}_6\text{H}_{12}\text{N}_4$ (Hexamethylenetetramine) (100)	
$\text{C}_7\text{H}_6\text{O}_2$ (Benzoic acid), 25° (78)	
$\text{C}_7\text{H}_6\text{O}_3$ (Salicylic acid), 25° (78)	
$\text{H}_3\text{BO}_3$ , 25° (78)	
$\text{MgCl}_2$ , 18° (40)	
$\text{CaCl}_2$ , 25° (49)	
$\text{LiCl}$ , 25° (49)	
$\text{NaCl}$ , 18° (82); 25° (30, 49)	
	Br
KBr, 0° (68)	
	HBr
$\text{SO}_2$ (6)	
	I
$\text{H}_3\text{AsO}_4$ , 25° (113)	
KI, 25° (31)	
	$\text{HIO}_3$
$\text{MoO}_3$ , 25° (114)	
	$\text{H}_2\text{SO}_4$
$\text{C}_2\text{H}_6\text{O}$ (Ethyl alcohol), 0, 12° (80)	
$\text{C}_3\text{H}_6\text{O}$ (Acetone) (81)	
$\text{C}_6\text{H}_{12}\text{N}_4$ (Hexamethylenetetramine) (100)	
$\text{ZnSO}_4$ , 20–40° (109)	
$\text{CuSO}_4$ , 25° (11); 25, 45° (95); 25, 40, 60° (110)	
$\text{MgSO}_4$ , 18° (40)	
$\text{KHSO}_4$ , 25° (8)	
	$\text{NH}_3$
$\text{NH}_4\text{Cl}$ , 0, 25° (4)	
$\text{C}_2\text{H}_6\text{O}$ (Ethyl alcohol), 18° (55)	
$\text{NaOH}$ , 0, 25° (4)	
	$\text{HNO}_3$
$\text{Bi}(\text{NO}_3)_3$ , 25° (94)	
$\text{CH}_4\text{N}_2\text{O}$ (Urea), 30° (45)	
$\text{C}_6\text{H}_{12}\text{N}_4$ (Hexamethylenetetramine) (100)	
$\text{C}_7\text{H}_6\text{O}_2$ (Benzoic acid), 25° (78)	

$\text{HgNO}_3$ , 20° (105)	
$\text{CrO}_3$ , 25° (45)	
$\text{H}_3\text{BO}_3$ , 25° (78)	
$\text{Mg}(\text{NO}_3)_2$ , 18° (40)	
	$\text{NH}_4\text{OH}$
$\text{NH}_4\text{Cl}$ , 25° (57)	
$\text{CH}_4\text{N}_2\text{O}$ (Urea), 25° (33)	
$\text{C}_2\text{H}_4\text{O}_3$ (Glycolic acid), 25° (36)	
$\text{C}_3\text{H}_6\text{O}_3$ (Lactic acid), 25° (36)	
$\text{C}_4\text{H}_8\text{O}_3$ ( $\alpha$ -Hydroxybutyric acid), 25° (36)	
$\text{C}_4\text{H}_8\text{O}_3$ ( $\alpha$ -Hydroxyisobutyric acid), 25° (36)	
$\text{H}_2\text{SiO}_3$ , 25° (105.1)	
$\text{AgNO}_3$ , 25° (57)	
$\text{Al}(\text{OH})_3$ , 0, 25° (63)	
$\text{CaCl}_2$ , 25° (57)	
	$\text{NH}_4\text{Cl}$
$\text{CH}_4\text{O}$ (Methyl alcohol), 0, 25° (4, 5)	
$\text{CH}_4\text{N}_2\text{S}$ (Thiourea), 25° (99)	
$\text{C}_2\text{H}_6\text{O}$ (Ethyl alcohol), 0, 25° (4, 5); 18° (55)	
$\text{C}_3\text{H}_8\text{O}$ (Propyl alcohol), 0, 25° (5)	
$\text{NiSO}_4$ , 25° (56)	
$\text{MgCl}_2$ , 0–35° (115)	
$\text{CaCl}_2$ , 25° (87)	
$\text{NaCl}$ , 25° (88)	
KCl, 18° (40); 12, 25° (73); 25° (87)	
	$\text{NH}_4\text{Br}$
$\text{CH}_4\text{N}_2\text{S}$ (Thiourea), 25° (99)	
$\text{C}_3\text{H}_8\text{O}_3$ (Glycerol) (67)	
	$\text{NH}_4\text{I}$
$\text{C}_3\text{H}_8\text{O}_3$ (Glycerol), 25–45° (42, 66)	
	$(\text{NH}_4)_2\text{SO}_4$
$\text{CH}_4\text{N}_2\text{S}$ (Thiourea), 25° (99)	
$\text{MgSO}_4$ , 18° (40)	
	$\text{NH}_4\text{NO}_3$
$\text{CH}_4\text{N}_2\text{S}$ (Thiourea), 25° (99)	
$\text{AgNO}_3$ (103)	
$\text{Mg}(\text{NO}_3)_2$ , 18° (40)	
$\text{NaNO}_3$ , 25° (88)	
	$\text{H}_3\text{PO}_4$
$\text{C}_6\text{H}_6\text{O}_2$ (Pyrocatechol), 25° (17)	
$\text{C}_6\text{H}_6\text{O}_2$ (Resorcinol), 25° (17)	
$\text{C}_6\text{H}_6\text{O}_2$ (Hydroquinol), 25° (17)	
$\text{C}_6\text{H}_6\text{O}_2$ (Pyrogallol), 25° (17)	
$\text{C}_6\text{H}_8\text{O}_7$ (Citric acid) (93)	
$\text{FeCl}_3$ , 18° (43)	
$\text{MoO}_3$ , 25° (99, 114)	
$\text{AlCl}_3$ , 18° (43)	
$\text{BeSO}_4$ , 18° (43)	
	$\text{H}_3\text{AsO}_4$
$\text{C}_6\text{H}_8\text{O}_7$ (Citric acid), 18° (93)	
$\text{FeCl}_3$ , 18° (43)	
$\text{MoO}_3$ , 25° (114)	
$\text{AlCl}_3$ , 18° (43)	
	$\text{Zr}(\text{NO}_3)_2$
$\text{K}_2\text{SO}_4$ , 25° (111)	



Pb(NO <sub>3</sub> ) <sub>2</sub> , 25° (60)	Pb(IO <sub>3</sub> ) <sub>2</sub>
KIO <sub>3</sub> , 25° (60)	
KNO <sub>3</sub> , 25° (60)	
Tl <sub>2</sub> SO <sub>4</sub> , 25° (84)	TiClO <sub>3</sub>
H <sub>3</sub> BO <sub>3</sub> , 25° (11)	ZnSO <sub>4</sub>
H <sub>3</sub> BO <sub>3</sub> + NaCl, 25° (11)	
KCl, 25° (104)	CdCl <sub>2</sub>
	CdI <sub>2</sub>
C <sub>3</sub> H <sub>6</sub> O (Acetone), 0, 25° (70, 71)	
KI, 0, 35° (115); 25° (104)	Cd(CN) <sub>2</sub>
KCN, 18° (96)	HgCl <sub>2</sub>
NaCl, 25° (104)	
KCl, 25° (104)	HgI <sub>2</sub>
KI, 18° (96)	CuCl <sub>2</sub>
NaCl (110)	CuSO <sub>4</sub>
CaSO <sub>4</sub> , 25° (59)	
Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> , 18, 30, 50° (48)	
K <sub>2</sub> SO <sub>4</sub> , 18° (96)	CuCNS
KCNS, 18° (44)	AgI
KI, 18° (96)	AgNO <sub>3</sub>
CH <sub>4</sub> N <sub>2</sub> O (Urea), 25° (57)	
CH <sub>4</sub> N <sub>2</sub> S (Thiourea), 25° (57, 99)	
C <sub>2</sub> H <sub>6</sub> O (Ethyl alcohol), 25° (57)	
C <sub>2</sub> H <sub>7</sub> NO <sub>2</sub> (Urethane), 25° (57)	
C <sub>5</sub> H <sub>5</sub> N (Pyridine), 25° (57)	
C <sub>6</sub> H <sub>14</sub> O <sub>6</sub> (Mannitol), 25° (57)	
	FeCl <sub>3</sub>
AlCl <sub>3</sub> , 25° (73)	
K <sub>2</sub> SO <sub>4</sub> , 25° (111)	CoCl <sub>2</sub>
CH <sub>3</sub> O (Methyl alcohol), 20° (58); 0, 25° (69, 79)	
C <sub>2</sub> H <sub>6</sub> O (Ethyl alcohol), 20° (58); 0, 25° (69, 79)	
C <sub>3</sub> H <sub>8</sub> O <sub>3</sub> (Glycerol), 25, 35° (72)	
KCN, 25° (101)	CoBr <sub>2</sub>
CaBr <sub>2</sub> , 0-35° (115)	NiCl <sub>2</sub>
NiSO <sub>4</sub> , 25° (56)	
NiSO <sub>4</sub> + H <sub>3</sub> BO <sub>3</sub> , 25° (11, 12, 56)	
NiSO <sub>4</sub> + H <sub>3</sub> BO <sub>3</sub> + NaCl, 25° (11)	
KCN, 25° (101)	NiF <sub>2</sub>
NiSO <sub>4</sub> + H <sub>3</sub> BO <sub>3</sub> , 25° (12)	
NiSO <sub>4</sub> + H <sub>3</sub> BO <sub>3</sub> + MgSO <sub>4</sub> , 25° (12)	
NiSO <sub>4</sub> + H <sub>3</sub> BO <sub>3</sub> + Na <sub>2</sub> SO <sub>4</sub> , 25° (12)	
	NiSO <sub>4</sub>
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> , 25° (56)	
MgSO <sub>4</sub> , 25° (56)	
NaCl, 25° (56)	
NaF, 25° (56)	
Na <sub>2</sub> SO <sub>4</sub> , 25° (56)	
K <sub>2</sub> SO <sub>4</sub> , 25° (56)	

KCNS, 25° (9)	Cr(NO <sub>3</sub> ) <sub>3</sub>
	MoO <sub>3</sub>
HCl, 25° (97)	
HCl + HIO <sub>3</sub> , 25° (97)	
HCl + H <sub>3</sub> PO <sub>4</sub> , 25° (97)	
HCl + H <sub>3</sub> AsO <sub>3</sub> , 25° (97)	
HCl + C <sub>2</sub> H <sub>2</sub> O <sub>4</sub> (Oxalic acid), 25° (97)	
HCl + C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> (Acetic acid), 25° (97)	
HCl + C <sub>2</sub> H <sub>4</sub> O <sub>3</sub> (Glycolic acid), 25° (97)	
HCl + C <sub>3</sub> H <sub>6</sub> O <sub>2</sub> (Propionic acid), 25° (97)	
HCl + C <sub>3</sub> H <sub>6</sub> O <sub>3</sub> (Lactic acid), 25° (97)	
HCl + C <sub>4</sub> H <sub>6</sub> O <sub>4</sub> (Succinic acid), 25° (97)	
HCl + C <sub>4</sub> H <sub>6</sub> O <sub>5</sub> (Malic acid), 25° (97)	
HCl + C <sub>4</sub> H <sub>6</sub> O <sub>6</sub> (Tartaric acid), 25° (97)	
HCl + C <sub>6</sub> H <sub>8</sub> O <sub>6</sub> (Tricarballic acid), 25° (97)	
HCl + C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> (Citric acid), 25° (97)	
HCl + C <sub>7</sub> H <sub>12</sub> O <sub>6</sub> (Quinic acid), 25° (97)	
HCl + C <sub>8</sub> H <sub>8</sub> O <sub>2</sub> (Phenylacetic acid), 25° (97)	
HCl + H <sub>3</sub> BO <sub>3</sub> , 25° (97)	
HIO <sub>3</sub> , 25° (99)	
HNO <sub>3</sub> , 25° (97)	
C <sub>2</sub> H <sub>2</sub> O <sub>4</sub> (Oxalic acid), 25° (99, 114)	
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> (Acetic acid), 25° (99, 114)	
C <sub>2</sub> H <sub>4</sub> O <sub>3</sub> (Glycolic acid), 25° (114)	
C <sub>3</sub> H <sub>6</sub> O <sub>2</sub> (Propionic acid), 25° (114)	
C <sub>3</sub> H <sub>6</sub> O <sub>3</sub> (Lactic acid), 25° (114)	
C <sub>4</sub> H <sub>6</sub> O <sub>4</sub> (Succinic acid), 25° (114)	
C <sub>4</sub> H <sub>6</sub> O <sub>5</sub> (Malic acid), 25° (114)	
C <sub>4</sub> H <sub>6</sub> O <sub>6</sub> (Tartaric acid), 25° (99, 114)	
C <sub>6</sub> H <sub>8</sub> O <sub>6</sub> (Tricarballic acid), 25° (114)	
C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> (Citric acid), 25° (99, 114)	
C <sub>6</sub> H <sub>14</sub> O <sub>6</sub> (Mannitol), 25° (99)	
C <sub>7</sub> H <sub>12</sub> O <sub>6</sub> (Quinic acid), 25° (114)	
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub> (Phenylacetic acid), 25° (114)	
C <sub>8</sub> H <sub>8</sub> O <sub>3</sub> (Mandelic acid), 25° (114)	
CrO <sub>3</sub> , 25° (97)	
H <sub>3</sub> BO <sub>3</sub> , 25° (99)	
	WO <sub>3</sub>
NaOH, 16° (38)	
Various tungstates are also given.	
	UO <sub>2</sub> Cl <sub>2</sub>
NaCl, 25° (46)	
	UO <sub>2</sub> SO <sub>4</sub>
Na <sub>2</sub> SO <sub>4</sub> , 25° (46)	
(46) also gives the oxalate, acetate, citrate and tartrate with the corresponding Na salts.	
	H <sub>3</sub> BO <sub>3</sub>
CH <sub>4</sub> N <sub>2</sub> O (Urea), 25° (24)	
C <sub>2</sub> H <sub>4</sub> O <sub>3</sub> (Glycolic acid), 25° (21)	
C <sub>2</sub> H <sub>5</sub> NO <sub>2</sub> (Glycocoll), 25° (24)	
C <sub>2</sub> H <sub>5</sub> N <sub>3</sub> O <sub>2</sub> (Biuret), 25° (24)	
C <sub>2</sub> H <sub>6</sub> O <sub>2</sub> (Glycol), 25° (23)	
C <sub>3</sub> H <sub>3</sub> N <sub>3</sub> O <sub>3</sub> (Cyanuric acid), 25° (24)	
C <sub>3</sub> H <sub>6</sub> O <sub>4</sub> (Glyceric acid), 25° (26)	
C <sub>3</sub> H <sub>7</sub> ClO <sub>2</sub> (α-Monochlorohydrin), 25° (14)	
C <sub>3</sub> H <sub>8</sub> O <sub>2</sub> (1, 3-Propanediol) (14)	
C <sub>3</sub> H <sub>8</sub> O <sub>3</sub> (Glycerol), 25° (14, 23)	
C <sub>4</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub> (Dialuric acid), 25° (24)	
C <sub>4</sub> H <sub>4</sub> N <sub>2</sub> O <sub>5</sub> (Alloxan), 25° (24)	
C <sub>4</sub> H <sub>4</sub> O <sub>6</sub> (Dihydroxymaleic acid), 25° (26)	
C <sub>4</sub> H <sub>6</sub> O <sub>2</sub> (Diacetyl), 25° (20)	
C <sub>4</sub> H <sub>6</sub> O <sub>5</sub> (Diglycolic acid), 25° (21)	
C <sub>4</sub> H <sub>6</sub> O <sub>6</sub> (dl- and d-Tartaric acid), 25° (18)	
C <sub>4</sub> H <sub>5</sub> NO <sub>5</sub> (Nitrotricarbinylmethane) (14)	



$C_4H_{10}O_2$  (1, 4-Butanediol) (14)  
 $C_4H_{10}O_2$  (Glyceryl  $\alpha$ -methyl ether) (65)  
 $C_5H_8N_4O_6$  (Uric acid glycol), 25° (24)  
 $C_5H_9NO_4$  (Glutamic acid), 25° (24)  
 $C_5H_{12}O_4$  (Pentaerythritol), 25° (14, 23)  
 $C_6H_4N_2O_6$  (3, 5-Dinitropyrocatechol), 25° (15)  
 $C_6H_6NO_4$  (4-Nitroresorcinol), 25° (15)  
 $C_6H_6O$  (Phenol), 25° (23)  
 $C_6H_6O_2$  (Pyrocatechol), 25° (16, 23)  
 $C_6H_6O_2$  (Resorcinol), 25° (23)  
 $C_6H_6O_2$  (Hydroquinol), 25° (23)  
 $C_6H_6O_2$  (Phloroglucinol), 25° (23)  
 $C_6H_6O_3$  (Pyrogallol), 25° (23)  
 $C_6H_{10}O_2$  (Divinylglycol), 25° (14)  
 $C_6H_{10}O_6$  (Gluconic lactone), 25° (26)  
 $C_6H_{12}O_7$  (Gluconic acid), 25° (26)  
 $C_6H_{14}O_2$  (Pinacol), 25° (14)  
 $C_6H_{14}O_6$  (Sorbitol), 25° (14)  
 $C_6H_{14}O_6$  (Mannitol) (2); 25° (65)  
 $C_7H_6O_4$  (3, 4-Dihydroxybenzoic acid), 25° (15)  
 $C_7H_6O_6$  (3, 4, 5-Trihydroxybenzoic acid), 25° (15)  
 $C_8H_8N_4O_8$  (Alloxantin), 25° (24)  
 $C_8H_8O_2$  (*dl*- and *d*-Mandelic acid), 25° (18)  
 $C_8H_{16}O_3$  ( $\alpha$ -Hydroxycaprylic acid), 25° (26)  
 $C_8H_{18}O_6$  ( $\epsilon$ ,  $\zeta$ -Dimethylmannitol), 25° (65)  
 $C_8H_{10}O_3$  ( $\beta$ -Phenyl- $\alpha$ -hydroxypropionic acid), 25° (21)  
 $C_8H_{10}O_4$  ( $\beta$ -Phenyl- $\beta$ -hydroxypropionic acid), 25° (21)  
 $C_8H_{10}O_4$  ( $\beta$ -Phenyl- $\alpha$ ,  $\beta$ -dihydroxypropionic acid) (19)  
 $C_8H_{12}O_3$  (Glyceryl  $\alpha$ -phenyl ether) (14)  
 $C_8H_{18}O_6$  (Mannitol monoacetone) (65)  
 $C_{10}H_8O_2$  (1, 2-Dihydroxynaphthalene), 25° (15, 16)  
 $C_{10}H_8O_2$  (2, 3-Dihydroxynaphthalene), 25° (16)  
 $C_{10}H_{22}O_6$  ( $\beta$ ,  $\gamma$ ,  $\epsilon$ ,  $\zeta$ -Tetramethylmannitol), 25° (65)  
 $C_{10}H_{22}O_6$  ( $\gamma$ ,  $\delta$ ,  $\epsilon$ ,  $\zeta$ -Tetramethylmannitol), 25° (65)  
 $C_{11}H_{24}O_6$  (Pentamethylmannitol), 25° (65)  
 $C_{12}H_{22}O_6$  (Mannitol diacetone), 25° (65)  
 $HBF_4 + Pb(BF_4)_2$ , 25° (13)  
 $KF$ , 25° (1)

**Al(OH)<sub>3</sub>**

$Mg(OH)_2$ , 25° (62)  
 $Ca(OH)_2$ , 25° (62)  
 $Sr(OH)_2$ , 25° (62)  
 $Ba(OH)_2$ , 25° (62)  
 $NaOH$ , 0, 25° (63)  
 $K_2SO_4$ , 0–35° (115)

**Th(SO<sub>4</sub>)<sub>2</sub>**

$K_2SO_4$ , 20° (7)

**La(IO<sub>3</sub>)<sub>3</sub>**

$La(NO_3)_3$ , 25° (60)  
 $NaNO_3$ , 25° (60)  
 $KIO_3$ , 25° (60)

**BeO**

$C_3H_5O_2$  (Lactic acid), 25° (34)

**Be(OH)<sub>2</sub>**

$C_2H_4O_2$  (Glycolic acid), 25° (35)  
 $C_4H_8O_3$  (Hydroxyisobutyric acid), 25° (35)

**MgCl<sub>2</sub>**

$CaCl_2$ , 25° (49, 73, 87)  
 $BaCl_2$ , 18° (47)  
 $Ba(NO_3)_2$ , 18° (47)  
 $NaCl$ , 18° (47); 25° (49, 88)  
 $KCl$ , 18° (40, 47); 25° (87)

**Mg(ClO<sub>3</sub>)<sub>2</sub>**

$NaClO_3$ , 18° (40)

**MgBr<sub>2</sub>**

$KBr$ , 18° (40); 0–35° (115)

**MgSO<sub>4</sub>**

$CaSO_4$ , 25° (59)  
 $Na_2SO_4$ , 18° (40)  
 $K_2SO_4$ , 18° (40)

**Mg(NO<sub>3</sub>)<sub>2</sub>**

$Ca(NO_3)_2$ , 25° (73, 88)  
 $Sr(NO_3)_2$ , 25° (73)  
 $NaNO_3$ , 25° (88)  
 $KNO_3$ , 18° (40)

**Ca(OH)<sub>2</sub>**

$CH_2N_2$  (Cyanamide), 25° (76)  
 $C_6H_{12}O_6$  (Dextrose), 25° (92)  
 $C_6H_{12}O_6$  (Levulose), 25° (92)

**CaCl<sub>2</sub>**

$CH_4O$  (Methyl alcohol), 25° (57)  
 $C_2H_6O$  (Ethyl alcohol), 25° (57)  
 $Ca(NO_3)_2$ , 25° (73)  
 $SrCl_2$ , 25° (73)  
 $BaCl_2$ , 18° (47)  
 $Ba(NO_3)_2$ , 18° (47)  
 $SrCl_2$ , 25° (87)  
 $NaCl$  (47); 25° (87, 88)  
 $KCl$ , 25° (73, 87)

**CaSO<sub>4</sub>**

$KNO_3$ , 25° (59)

**Ca(NO<sub>3</sub>)<sub>2</sub>**

$Sr(NO_3)_2$ , 25° (88)  
 $NaCl$ , 25° (88)  
 $NaNO_3$ , 25° (88)  
 $KCl$ , 25° (88)

**Ba(OH)<sub>2</sub>**

$C_6H_{12}O_6$  (Dextrose), 25° (92)  
 $C_6H_{12}O_6$  (Levulose), 25° (92)

**BaCl<sub>2</sub>**

$Ba(NO_3)_2$ , 18° (47)  
 $SrCl_2$ , 25° (104)  
 $NaCl$ , 18° (47)  
 $NaNO_3$ , 18° (47)

**SrCl<sub>2</sub>**

$C_3H_8O_3$  (Glycerol) (67)  
 $NaCl$ , 25° (88)  
 $KCl$ , 25° (87)

**Sr(NO<sub>3</sub>)<sub>2</sub>**

$NaNO_3$ , 25° (88)  
 $KNO_3$ , 25° (88)

**LiCl**

$CH_4O$  (Methyl alcohol), 0, 26° (4)  
 $CH_4N_2O$  (Urea), 20° (86)  
 $C_2H_6O$  (Ethyl alcohol), 0, 26° (4)  
 $C_2H_6O_2$  (Glycol), 0, 26° (4)  
 $C_3H_8O$  (Propyl alcohol), 0, 26° (4)  
 $C_3H_8O_3$  (Glycerol), 20° (86); 0, 26° (4)  
 $C_{12}H_{22}O_{11}$  (Sucrose), 20° (86)  
 $KCl$ , 25° (49)

**LiBr**

$C_3H_8O_3$  (Glycerol), 25, 35° (72)  
 $NaBr$ , 25° (73)

**LiNO<sub>3</sub>**

$CH_4O$  (Methyl alcohol) +  $C_3H_8O$  (Acetone), 0, 25° (71)  
 $C_3H_8O$  (Acetone), 0, 25° (71); 0° (70)  
 $C_5H_5N$  (Pyridine), 25° (61)



## NaOH

CH<sub>2</sub>N<sub>2</sub> (Cyanamide), 25° (76)  
 C<sub>2</sub>H<sub>5</sub>O (Ethyl alcohol), 0, 25° (4); 25° (57)  
 C<sub>3</sub>H<sub>7</sub>O (Propyl alcohol), 0, 25° (4)  
 C<sub>4</sub>H<sub>12</sub>INO (Trimethylmethoxyammonium iodide), 25° (108)  
 C<sub>5</sub>H<sub>14</sub>INO (Trimethylethoxyammonium iodide), 25° (108)  
 C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> (Dextrose), 25° (92)  
 C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> (Levulose), 25° (92)  
 C<sub>2</sub>H<sub>3</sub>O<sub>2</sub>Na (Na acetate), 2, 4° (75)  
 Na<sub>2</sub>B<sub>4</sub>O<sub>7</sub> (Borax), 0, 18° (91)

## NaCl

CH<sub>3</sub>O (Methyl alcohol), 0, 25° (5)  
 CH<sub>4</sub>N<sub>2</sub>O (Urea), 25° (57)  
 C<sub>2</sub>H<sub>5</sub>O (Ethyl alcohol), 0, 25° (5)  
 C<sub>3</sub>H<sub>7</sub>O (Propyl alcohol), 0, 25° (5)  
 C<sub>3</sub>H<sub>7</sub>O (Isopropyl alcohol), 0, 25° (5)  
 C<sub>3</sub>H<sub>5</sub>O<sub>3</sub> (Glycerol), 25° (90)  
 C<sub>4</sub>H<sub>6</sub>O<sub>6</sub> (Tartaric acid), 25° (102)  
 C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> (Glucose), 25° (4, 51)  
 C<sub>6</sub>H<sub>14</sub>O<sub>6</sub> (Mannitol), 25° (90)  
 C<sub>7</sub>H<sub>8</sub>NO<sub>3</sub>S (Saccharin), 18° (10)  
 C<sub>7</sub>H<sub>14</sub>O<sub>6</sub> (α-Methylglucoside), 25° (4, 51)  
 C<sub>7</sub>H<sub>14</sub>O<sub>6</sub> (β-Methylglucoside), 25° (51)  
 C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> (Sucrose), 25° (4, 51)  
 C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> (Lactose), 25° (51)  
 C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> (Melibiose), 25° (4, 51)  
 C<sub>18</sub>H<sub>32</sub>O<sub>16</sub> (Raffinose), 25° (4, 51)  
 Congo red, 18° (27)  
 Na<sub>2</sub>SO<sub>4</sub>, 25° (104)  
 NaNO<sub>3</sub>, 18° (47)  
 KCl, 18° (47); 25° (87, 104, 107)  
 K<sub>2</sub>SO<sub>4</sub>, 18° (47)  
 KNO<sub>3</sub>, 18° (47); 25° (88)

## NaBr

KBr, 25° (107)

## NaI

KI, 18° (47); 25° (107)

Na<sub>2</sub>SO<sub>4</sub>

K<sub>2</sub>SO<sub>4</sub>, 18° (47)  
 KNO<sub>3</sub>, 18° (47)

NaNO<sub>3</sub>

C<sub>3</sub>H<sub>5</sub>O<sub>3</sub> (Glycerol) (67)  
 C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> (Dextrose), 25° (51)  
 C<sub>7</sub>H<sub>14</sub>O<sub>6</sub> (α-Methylglucoside), 25° (51)  
 C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> (Sucrose), 25° (51)  
 KCl, 25° (88)  
 KNO<sub>3</sub>, 18° (47); 25° (88)

Na<sub>2</sub>CO<sub>3</sub>

K<sub>2</sub>SO<sub>4</sub>, 18° (47)  
 K<sub>2</sub>CO<sub>3</sub>, 18° (47)

Conductivities of the Na derivatives of acetophenone, acetoxime, benzoin, benzophenone, chloral hydrate, phenol and succinimide in ethyl alcohol and water at 18° are given in (55).

## KOH

C<sub>2</sub>H<sub>5</sub>O (Ethyl alcohol), 18° (55)  
 C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> (Dextrose), 25° (92)  
 C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> (Levulose), 25° (92)  
 C<sub>16</sub>H<sub>31</sub>O<sub>2</sub>K (K palmitate), 20, 90° (54)

## KCl

CH<sub>4</sub>N<sub>2</sub>O (Urea), 20° (86); 25° (57)  
 CH<sub>4</sub>N<sub>2</sub>S (Thiourea), 25° (57, 99)  
 CH<sub>3</sub>O (Methyl alcohol), 0, 25° (4, 5)  
 C<sub>2</sub>H<sub>4</sub>O (Acetaldehyde), 0, 25° (4)  
 C<sub>2</sub>H<sub>5</sub>O (Ethyl alcohol), 0, 25° (4, 5); 25° (57)  
 C<sub>3</sub>H<sub>5</sub>O<sub>3</sub> (Glycerol), 0, 25° (4)

C<sub>3</sub>H<sub>6</sub>O (Acetone), 0, 25° (4); 25° (57)  
 C<sub>3</sub>H<sub>7</sub>NO<sub>2</sub> (Urethane), 25° (57)  
 C<sub>3</sub>H<sub>7</sub>O (Propyl alcohol), 0, 25° (4, 5)  
 C<sub>3</sub>H<sub>5</sub>O<sub>3</sub> (Glycerol), 0, 25° (4); 25, 35, 45° (67); 20° (86)  
 C<sub>4</sub>H<sub>6</sub>O<sub>4</sub> (Succinic acid), 25° (102)  
 C<sub>4</sub>H<sub>10</sub>O (Isobutyl alcohol), 0, 25° (4)  
 C<sub>4</sub>H<sub>10</sub>O (Ethyl ether), 0° (4); 25° (57)  
 C<sub>5</sub>H<sub>5</sub>N (Pyridine), 25° (57)  
 C<sub>6</sub>H<sub>12</sub>O<sub>3</sub> (Paraldehyde), 0° (4)  
 C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> (Dextrose), 25° (4, 51)  
 C<sub>6</sub>H<sub>14</sub>O<sub>6</sub> (Mannitol), 25° (57); 20° (86)  
 C<sub>7</sub>H<sub>14</sub>O<sub>6</sub> (α-Methylglucoside), 25° (4, 51)  
 C<sub>7</sub>H<sub>14</sub>O<sub>6</sub> (β-Methylglucoside), 25° (51)  
 C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> (Lactose), 25° (51)  
 C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> (Melibiose), 25° (4, 51)  
 C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> (Sucrose), 25° (4, 51), 20° (86)  
 C<sub>18</sub>H<sub>32</sub>O<sub>16</sub> (Raffinose), 20° (86); 25° (4, 51)  
 C<sub>36</sub>H<sub>62</sub>O<sub>31</sub> (Inulin), 20° (86)  
 KClO<sub>4</sub>, 25° (84)  
 K<sub>2</sub>SO<sub>4</sub>, 25° (84)  
 KNO<sub>3</sub>, 18° (3); 25° (88)

## KBr

CH<sub>3</sub>O (Methyl alcohol), 0, 25° (4)  
 C<sub>2</sub>H<sub>5</sub>O (Ethyl alcohol), 0, 25° (4)  
 C<sub>3</sub>H<sub>5</sub>O<sub>3</sub> (Glycerol), 0, 25° (4)  
 C<sub>3</sub>H<sub>7</sub>O (Propyl alcohol), 0, 25° (4)  
 C<sub>3</sub>H<sub>5</sub>O<sub>3</sub> (Glycerol), 0, 25° (4)

## KI

CH<sub>3</sub>O (Methyl alcohol), 0, 25° (4, 69, 79)  
 C<sub>2</sub>H<sub>5</sub>O (Ethyl alcohol), 0, 25° (4, 69, 79)  
 C<sub>3</sub>H<sub>5</sub>O<sub>3</sub> (Glycerol), 0, 25° (4)  
 C<sub>3</sub>H<sub>5</sub>O<sub>3</sub> (Glycerol) (72)  
 C<sub>4</sub>H<sub>9</sub>NI (Tetraethylammonium iodide), 25° (89)

K<sub>2</sub>SO<sub>4</sub>

C<sub>4</sub>H<sub>4</sub>O<sub>6</sub>K<sub>2</sub> (K tartrate) (28)

## RbCl

C<sub>3</sub>H<sub>6</sub>O (Acetone), 15–45° (41)

## RbBr

C<sub>3</sub>H<sub>6</sub>O (Acetone), 15–45° (41)  
 C<sub>3</sub>H<sub>5</sub>O<sub>3</sub> (Glycerol), 25–45° (42, 66)

## RbI

C<sub>3</sub>H<sub>6</sub>O (Acetone), 15–45° (41)

RbNO<sub>3</sub>

C<sub>3</sub>H<sub>6</sub>O (Acetone), 15–45° (41)

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## TRANSFERENCE NUMBERS OF ELECTROLYTES IN AQUEOUS SOLUTION

K. G. FALK

In the following tables the values given are in all cases the transference numbers of the cation multiplied by  $10^3$ , and except as otherwise noted are with respect to water as the reference substance. Concentrations,  $C$ , are in equivalents per liter except those marked "Wt.  $N$ " which are in equivalents per kg  $H_2O$ . For theoretical discussion of the numbers and methods of weighting results obtained by the gravimetric method, see Noyes and Falk, 1, 33: 1436; 11.

Les valeurs données dans les tables suivantes sont dans tous les cas, les nombres de transport des cations multipliés par  $10^3$  et, à moins d'une autre indication, se rapportent à l'eau comme substance de référence. Les concentrations,  $C$ , sont exprimées en équivalents par litre, à l'exception de celles marquées "Wt.  $N$ " qui sont exprimées en équivalents par kg  $H_2O$ . Pour la discussion théorique des nombres et des méthodes d'appréciation des résultats par la méthode gravimétrique, voir Noyes and Falk, 1, 33: 1436; 11.

In den folgenden Tabellen stellen alle angegebenen Werte die Überföhrungszahlen des Kations multipliziert mit  $10^3$  dar. Sie gelten, stets, wenn nicht etwas anderes bemerkt, in Bezug auf Wasser. Die Konzentrationen,  $C$ , sind in Äquivalenten pro Liter angegeben, mit Ausnahme der Stellen, wo die Bezeichnung "Wt.  $N$ " steht, welche Äquivalente pro kg Wasser bedeutet. Die theoretischen Besprechungen der Zahlen und der Methoden zur Abschätzung der Ergebnisse nach der gravimetrischen Methode, findet man in der Abhandlung von Noyes and Falk, 1, 33: 1436; 11.

I valori riportati nelle tabelle seguenti rappresentano sempre il numero di trasporto del catione moltiplicato per  $10^3$ , e, salvo indicazioni contrarie, si riferiscono all'acqua. Le concentrazioni,  $C$ , sono in equivalenti per litro, eccettuati i casi contrassegnati con "Wt.  $N$ " nei quali le concentrazioni sono espresse in equivalenti per kg di acqua. Per la discussione teorica dei numeri e circa l'apprezzamento dei risultati ottenuti col metodo gravimetrico, vedi Noyes and Falk, 1, 33: 1436; 11.

TABLE 1.—GRAVIMETRIC METHOD

Electrolyte	$t$ , °C	$10^3 n_k$	$C \times 10^3$	Lit.	Electrolyte	$t$ , °C	$10^3 n_k$	$C \times 10^3$	Lit.
Uni-univalent electrolytes									
HF.....	v. Table 2 (7)				NaOH.....	25	201	25- 40	(2)
HCl.....	v. Table 2 (2, 14, 22, 24, 43, 44, 45, 47, 48, 56)				NaCl.....	v. Table 2 (2, 22, 24, 59, 60)			
HI.....	25	825	60- 80	(55)	NaBr.....	v. Table 2 (2, 24)			
		828	80- 150		NaNO <sub>3</sub> .....	19	371	40- 60	(2)
		825	150- 250		KCl.....	v. Table 2 (2, 24, 47, 53, 56, 59)			
HNO <sub>3</sub> .....	v. Table 2 (2, 24, 44)				KBr.....	v. Table 2 (24)			
NH <sub>4</sub> Cl.....	v. Table 2 (2, 24)				KI.....	25	495	40- 60	(2)
TiCl.....	22	484	8- 15	(2)	KMnO <sub>4</sub> .....	23	441	40- 60	(2)
AgClO <sub>3</sub> .....	25	499	15- 25	(30)	RbCl.....	22	485	40- 60	(2)
AgClO <sub>4</sub> .....	25	486	15- 25	(30)	CsCl.....	20	492	40- 60	(2)
AgNO <sub>3</sub> .....	25	481	2- 8	(13)		25	485	1.1 Wt. $N$	(60)
		461	8- 15		Uni-bivalent electrolytes				
AgNO <sub>3</sub> .....	v. Table 2 (2, 24, 25, 26, 29, 30, 41)				H <sub>2</sub> SO <sub>4</sub> .....	v. also Table 2 (2, 24, 57, 61)			
Ag <sub>2</sub> C <sub>2</sub> H <sub>3</sub> O <sub>4</sub> .....	0, 24, 28, 46, 96°C, v. (2, 30, 41)					96	696	40- 60	(2)
LiCl.....	18	v. Table 2		(24, 47)	Tl <sub>2</sub> SO <sub>4</sub> .....	v. Table 2 (2, 15)			
	25	324	40- 60	(2)	Ag <sub>2</sub> S <sub>2</sub> O <sub>6</sub> .....	0-30	396	15- 25	(30)
		276	1.25 Wt. $N$	(59)	Ag <sub>2</sub> SiF <sub>6</sub> .....	22	525	25- 40	(30)
	97	390	40- 60	(2)	Na <sub>2</sub> SO <sub>4</sub> .....	v. Table 2 (24)			
					K <sub>2</sub> SO <sub>4</sub> .....	v. Table 2 (24, 42)			
					Pb(NO <sub>3</sub> ) <sub>2</sub> .....	v. Table 2 (15)			



TABLE 1.—(Continued)				
Electrolyte	<i>t</i> , °C	10 <sup>3</sup> <i>n<sub>k</sub></i>	<i>C</i> × 10 <sup>3</sup>	Lit.
CdCl <sub>2</sub> .....	<i>v. also</i> Table 2 (24)			
	8	433	250– 400	(2)
	25	431	40– 60	(2)
CdBr <sub>2</sub> .....	96	525	40– 60	(2)
	<i>v. Table</i> 2 (24)			
	<i>v. Table</i> 2 (24)			
CuCl <sub>2</sub> .....	23	405	40– 60	(2)
CuBr <sub>2</sub> .....	25	445	150– 250	(8)
MnCl <sub>2</sub> .....	18	387	40– 60	(2)
CoCl <sub>2</sub> .....	18	404	40– 60	(2)
CoBr <sub>2</sub> .....	25	409	150– 250	(8)
MgCl <sub>2</sub> .....	21	385	40– 60	(2)
Ca(OH) <sub>2</sub> .....	25	214	25– 40	(2)
CaCl <sub>2</sub> .....	<i>v. also</i> Table 2 (2, 53)			
	49	445	8– 15	(2)
	96	470	8– 15	(2)
Ca(NO <sub>3</sub> ) <sub>2</sub> .....		426	80– 150	(2)
		451	150– 250	(2)
	18	450	2– 8	(53)
SrCl <sub>2</sub> .....	20	433	250– 400	(2)
BaCl <sub>2</sub> .....	<i>v. Table</i> 2 (2, 22, 24, 42)			
Ba(NO <sub>3</sub> ) <sub>2</sub> .....	<i>v. Table</i> 2 (42)			
Cu (C <sub>7</sub> H <sub>5</sub> O <sub>2</sub> ) <sub>2</sub> , Salicylate	25	626	10– 30	(20)
AgC <sub>10</sub> H <sub>7</sub> SO <sub>3</sub> .....	25–30	612	8– 25	(30)
AgC <sub>9</sub> H <sub>11</sub> SO <sub>3</sub> , Pseudo-cumenesulfonate.....	0	727	15– 25	(30)
	24	707	15– 25	(30)
	29	705	15– 25	(30)
AgC <sub>2</sub> H <sub>5</sub> SO <sub>4</sub> .....	25	616	2– 8	(30)
		613	15– 25	(30)
		653	15– 25	(30)
AgC <sub>6</sub> H <sub>5</sub> SO <sub>3</sub> .....	25			
Cobaltammine complex salts.....	15–20		8– 40	(31)
(Na <sub>2</sub> O) <sub>x</sub> (SiO <sub>2</sub> ) <sub>y</sub> .....				(21)
Bi-bivalent electrolytes				
CdSO <sub>4</sub> .....	<i>v. Table</i> 2 (24)			
CuSO <sub>4</sub> .....	<i>v. also</i> Table 2 (24)			
	0	385	8– 15	(2)
		389	80– 150	
	11	316	600– 800	(22)
		304	800–1000	(2)
	50	393	80– 150	
MgSO <sub>4</sub> .....	<i>v. Table</i> 2 (2, 22, 24)			
CaSO <sub>4</sub> .....	18	441	2– 8	(53)

TABLE 2.—GRAVIMETRIC METHOD, BEST VALUES For literature, <i>v. Table</i> 1										
Electrolyte	<i>t</i> , °C	<i>C</i> × 10 <sup>3</sup>								
		5	10	20	50	100	200	300	500	1000
HF.....	25			860	845	821	787	763	732	694
HCl.....	0	847	846	844	839	834				
	10	840	840	841						
	18	832	833	833	834	835	837	838	840	844
	30		822	822	822					
	50		801							
	76					781				
HNO <sub>3</sub> .....	96		748							
	20	839	840	841	844					
	0		489	489						
NH <sub>4</sub> Cl.....	18		492	492	492					
	30		495	495						
	0			461						
AgNO <sub>3</sub> .....	18		471	471	471	471				
	25		477	477	477					
	30	481	481	481	481	481	481	481	481	

TABLE 2.—(Continued)										
Electrolyte	<i>t</i> , °C	<i>C</i> × 10 <sup>3</sup>								
		5	10	20	50	100	200	300	500	1000
LiCl.....	18		332	328	320	313	304	299		
NaCl.....	0	387	387	387	386	385				
	18	397	397	396	393	390	385	380	374	365
	30	404	404	404	404	403				
NaBr.....	96				442	442	442			
	18	395	395	395						
	0	493	493	493	493	492	491			
KCl.....	10		495	495	495	495				
	18	496	496	496	496	495	494	493	492	490
	30	498	498	498	498	497	496			
KBr.....	18		495	495						
H <sub>2</sub> SO <sub>4</sub> .....	8			835	835	835				
	20			822	822	822	820	818	816	812
	32			808	808	808				
Pb(NO <sub>3</sub> ) <sub>2</sub> .....	25				487	487				
Tl <sub>2</sub> SO <sub>4</sub> .....	25				478	476				
CdCl <sub>2</sub> .....	18	430	430	430	430	430				
CdBr <sub>2</sub> .....	18	430	430	430	430	429	410	389	350	222
CdI <sub>2</sub> .....	18	445	444	442	396	296	127	46	3	
CaCl <sub>2</sub> .....	20	440	432	424	413	404	395	389		
	25				418	409				
	0	439	437	432						
BaCl <sub>2</sub> .....	16					420	408	401	391	
	25				438	427	415			
	30	445	444	443						
Ba(NO <sub>3</sub> ) <sub>2</sub> .....	50		475							
	25				456	456	456			
	18		392	390	383					
Na <sub>2</sub> SO <sub>4</sub> .....	18		494	492	490					
	25				496	494	493			
	18									
K <sub>2</sub> SO <sub>4</sub> .....	25									
	18		389	384	374	364	350	340	323	294
	18			375	375	373	361	348	327	
CuSO <sub>4</sub> .....	18	388	385	381	373					
	30		388	386	380					
MgSO <sub>4</sub> .....										

TABLE 3.—MOVING BOUNDARY METHOD (9, 10, 11, 12, 33, 34, 34.5, 35, 36, 37, 39, 50, 51, 52)						
Electrolyte	<i>C</i> × 10 <sup>3</sup>					
	20	50	100	50	100	200
Values of 10 <sup>3</sup> <i>n<sub>k</sub></i> , 18°C						
HCl.....	835		835	828	832	
HNO <sub>3</sub> *.....	846		855	840	844	849
NH <sub>4</sub> NO <sub>3</sub> .....					513	
NH <sub>4</sub> Cl.....	492		489		490	
NH <sub>4</sub> Br.....	483		481			
NH <sub>4</sub> I.....	489		484			
AgNO <sub>3</sub> .....				466	469	
NaOH.....			158			
NaCl.....		387	383		386	
NaBr.....		381	376			
NaI.....		381	376			
NaNO <sub>3</sub> .....					410	
KOH.....			257			
KCl.....	493		492		492	490
KClO <sub>3</sub> .....	534		536		537	
KClO <sub>4</sub> .....			523			
KBr.....	482		481		480	
					485	
KBrO <sub>3</sub> .....	567		570		570	
KI.....	487		486		483	



TABLE 3.—(Continued)

Electrolyte	$C \times 10^3$			$C \times 10^3$		
	20	50	100	50	100	200
Values of $10^3 n_k$ , 18°C						
Values of $10^3 n_k$ , 25°C						
KNO <sub>3</sub> .....	502		502		501 512	
RbCl.....	497		494			
RbBr.....	495		492			
RbI.....	498		497			
CsCl.....	504		500			
CsBr.....	497		493			
CsI.....	497		497			
H <sub>2</sub> SO <sub>4</sub> .....	833		828			
MgCl <sub>2</sub> .....		368	352			
MgBr <sub>2</sub> .....	385	368	350			
MgI <sub>2</sub> .....	388		350			
CaCl <sub>2</sub> .....	413		398		396	
CaBr <sub>2</sub> .....	409		396			
CaI <sub>2</sub> .....	416		400			
SrCl <sub>2</sub> .....	412		400		404	
SrBr <sub>2</sub> .....	410		392			
SrI <sub>2</sub> .....	416		393			
BaCl <sub>2</sub> .....	435		419		416	
BaBr <sub>2</sub> .....	422		408			
BaI <sub>2</sub> .....	426		415			
K <sub>2</sub> SO <sub>4</sub> .....	488		485		479	

\* 25°, 10°C = 10 or 20, 10<sup>3</sup>n<sub>k</sub> = 838.

TABLE 4.—ELECTROMOTIVE FORCE METHOD

Electrolyte	t, °C	$C \times 10^3$										Lit.
		5	10	20	30	50	100	200	300	500	1000	
HCl.....	18	832	832	832	832	832	832	832				(16, 38)
	25				830							(19)
LiCl.....	25	341	334	327	323	318	311	304	299	293	286	(34)
NaOH.....	25		203	197	194	189	183	177	174	169	163	(18)
KOH.....	25				263	263	263	263	263	263	263	(27, 28)
KCl.....	25	496	496	496	496	496	496	496	496	496	496	(1, 6, 38)
KBr.....	25	496	496	496	496	496	496	495	491	488	485	(46)
	30	496	496	496	496	496	496	495	492	489	486	(46)
	35	496	496	496	496	496	496	495	493	491	489	(46)
H <sub>2</sub> SO <sub>4</sub> .....	25						813					(17)
CuCl <sub>2</sub> .....	25		420	416	411	404	387	355	322	289	259	(32)
SrCl <sub>2</sub> .....	25		424	417	412	405	393	376	360	343	306	(32)
BaCl <sub>2</sub> .....	25		439	431	425	418	406	390	383	377	372	(32)

TABLE 5.—TRUE TRANSFERENCE NUMBERS AND RELATIVE HYDRATION VALUES

For critical review of the literature and some additional data, see (46.5)

Electrolyte	C, Wt. N	t, °C	Reference substance	10 <sup>3</sup> n <sub>k</sub>	Lit.
HCl.....	1.0-3.1	Room	Mannitol	844	(5)
			Resorcinol		
HCl.....	1.0	18		844	
HCl.....	2.5	18		825	
KCl.....	0.5	18		502	
KCl.....	1.0	18	Allyl alcohol	502	(56)
KCl.....	1.4	18		498	
KCl.....	1.9	18		496	
KCl.....	2.5	18		492	
KCl.....	1.24	25		495	
LiCl.....	1.28	25		304	(59)
NaCl.....	1.21	25	Raffinose	383	
NaCl.....	1.12	25		377	
CsCl.....	1.1	25		491	(60)

## Relative Hydration Values of the Ions

Average number of water molecules carried by the indicated ion combined as chloride as it moves through the solution.

HCl:  $N_w^{H^+} = 0.28 \pm 0.04 + 0.185N_w^{Cl^-}$ .

CsCl:  $N_w^{Cs^+} = 0.67 \pm 0.01 + 1.03N_w^{Cl^-}$ .

KCl:  $N_w^{K^+} = 1.3 \pm 0.2 + 1.02N_w^{Cl^-}$ .

NaCl:  $N_w^{Na^+} = 2.0 \pm 0.2 + 1.61N_w^{Cl^-}$ .

LiCl:  $N_w^{Li^+} = 4.7 \pm 0.4 + 2.29N_w^{Cl^-}$ .

TABLE 6.—MIXTURES OF ELECTROLYTES

Electrolytes	C	Tr. No. $\times 10^3$	Lit.
KCl	0.2	Cl <sup>-</sup>	(40)
K <sub>2</sub> SO <sub>4</sub>	0.2	289	
FeCl <sub>3</sub>	0.14	Fe'''	(23)
HCl	0.05-0.19	384	
FeCl <sub>3</sub>	0.44	Fe'''	
HCl	0.06-0.31	359	
FeCl <sub>3</sub>	1.16-1.32	Fe'''	
HCl	0.50-0.60	297	
FeCl <sub>3</sub>	0.16	Fe'''	
HCl	0.23	301	
FeCl <sub>3</sub>	0.16	Fe'''	
HCl	0.22	313	
FeCl <sub>2</sub>	0.17	Fe''	(54)
HCl	0.13	375	
FeCl <sub>2</sub>	0.49	Fe''	
HCl	0.12-0.18	326	
FeCl <sub>2</sub>	1.0	Fe''	
HCl	0.04-0.19	300	

## Electrolytes, KCl, NaCl

Total salt concentration 0.2N; concentration ratios, KCl:NaCl	Tr. No. $\times 10^3$	Lit.	Total salt concentration 0.2N; concentration ratios, KCl:NaCl	Tr. No. $\times 10^3$	Lit.
4:1	K <sup>+</sup> 369 Na <sup>+</sup> 63	(4)	1:2	K <sup>+</sup> 159 Na <sup>+</sup> 246	(4)
3:1	K <sup>+</sup> 372 Na <sup>+</sup> 84		1:3	K <sup>+</sup> 129 Na <sup>+</sup> 239	
2:1	K <sup>+</sup> 337 Na <sup>+</sup> 109		1:4	K <sup>+</sup> 108 Na <sup>+</sup> 288	
1:1	K <sup>+</sup> 260 Na <sup>+</sup> 163				

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## ELECTROLYTIC EMF

DUNCAN A. MACINNES, SPECIAL EDITOR

COMPLETE INDEX	INDEX COMPLET	GESAMT INDEX VERZEICHNIS	INDICE COMPLETO	PAGE
Standard cells and primary cells.	Piles étalons et éléments primaires	Normal-Elemente und Primär-Elemente.	Pile campione e pile primarie.....	312
Electrode potentials.	Potentiels des électrodes.	Einzelpotentiale.	Potenziali delle pile ad elettrodi.....	319
Emf of concentration cells.	F.e.m. des piles de concentration.	Elektromotorische Kraft von Konzentrations-Ketten.	F.e.m. delle pile di concentrazione.....	321
Chemical cells.	Piles chimiques.	Chemische-Zellen.	Pile chimiche.....	332
Oxidation and reduction cells.	Piles d'oxydation et de réduction.	Oxydations- und Reduktions-Ketten.	Pile di ossidazione e riduzione.....	333
Liquid junction potentials.	Potentiels de contact des junctions de liquides.	Flüssigkeits-Ketten.	Potenziali liquido-liquido..	338
Overvoltage.	Surtension.	Überspannung.	Sovratensione.....	339

## THE CHARACTERISTICS OF STANDARD CELLS AND OF PRIMARY CELLS

M. DEKAY THOMPSON

## CONTENTS

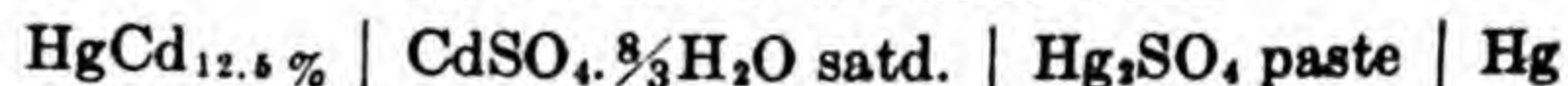
	PAGE
The Weston normal and the Weston unsaturated cadmium cells.....	312
Cadmium cells with halide electrolytes.....	314
The Clark cell.....	314
The Helmholtz cell.....	315
The mercury oxide cell.....	315
The lead chloride cell.....	315
The Cu-Hg cell.....	315
The Pb-Hg cell.....	315
Low-voltage normal cells.....	315
The LeClanché dry cell.....	315
The Féry Zn-C cell.....	317
Caustic soda cells.....	317
The Daniell Cu-Zn cell.....	318
The Grove and Bunsen nitric acid cells.....	318
The Poggendorff bichromate cell.....	318

## The Weston Normal Cell and the Weston Unsaturated Cell

**Definitions.**—The term "Weston Normal Cell" is used here to designate the cell which contains solid crystals of  $\text{CdSO}_4 \cdot \frac{8}{3}\text{H}_2\text{O}$  and which is used to maintain the standard of electromotive force. The term "Weston Unsaturated Cell" is here used to designate the cell which is made up with a solution of  $\text{CdSO}_4$  which is satu-

rated at 4°C and contains no excess of solid crystals of the sulfate. This cell is more generally used in practice since it has a lower temperature coefficient than the normal cell.

## THE WESTON NORMAL CELL



**Emf at 20°C.**—(a) Value in semi-absolute volts at 20.00°C, that is, the potential which exists between the terminals of a resistance of one international ohm when carrying a current of one absolute ampere: 1.01825; average deviation of mean = 0.00002.

This value is the arithmetical mean of the results from the following references: (1, 23, 25, 34, 50, 57, 62).

(b) Value in international volts, when the current through the international ohm is determined by a silver coulometer, the electrochemical equivalent of silver being taken as 1.11800 milligram per coulomb as defined by the International Congress of 1908.

Value recommended by a special technical committee to the International Committee on Electrical Units and Standards: 1.0183 international volt at 20°C (6).

Best average value: 1.018274 international volt at 20°C; average deviation of mean = 0.000003.

This average value is the weighted mean from the following references, with assigned weights equal to the square root of the number of observations, since the authors do not compute the precision measure in all cases (19, 25, 39, 40, 59, 67); cf. (58).



**The Temperature Coefficient.**— $E_t = E_{20} - 0.0000406(t - 20) - 0.00000095(t - 20)^2 + 0.00000001(t - 20)^3$ . Adopted by the International Conference on Electrical Units and Standards at London, 1908 (76).

**Construction.**—Normal cells are nearly always constructed in the H-form proposed by Lord Rayleigh (17, 29, 55, 75). Recently circular forms have been constructed and studied (30, 56).

**Heat of the Reaction in the Weston Cell.**— $\text{Cd} + \text{Hg}_2\text{SO}_4 + \frac{8}{3} \text{CdSO}_4 \cdot m\text{H}_2\text{O} = 2\text{Hg} + \frac{m}{m - \frac{8}{3}} \text{CdSO}_4 \cdot \frac{8}{3}\text{H}_2\text{O}$ , where  $m$  is the number of moles of water per mole of cadmium sulfate in the saturated solution.

The heat of this reaction is 47 561 g-cal<sub>15</sub> according to thermochemical measurements, and 47 437 from the electromotive force and its temperature coefficient. These values refer to 12.5% Cd in the amalgam (8, 10).

**Effect of Pressure on the Emf of the Weston Cell.**— $v$ . (13, 15).

**Influence of Ultra-violet Light on the Emf of the Weston Cell.**— $v$ . (52).

**Effect of Size of Grain of Mercurous Sulfate.**—Weston cells made

with finely divided mercurous sulfate (grain size of the order of magnitude of  $5\mu$  in diameter) have an electromotive force of 40 to 100 microvolt higher than those made with coarse mercurous sulfate (grain size 30 to  $360\mu$ ). Hysteresis is greatest with coarse, white mercurous sulfate and is less for acid than for neutral cells (72); cf. (66, 75).

**The Effect of Acidity on the Weston Cell.**—For the purpose of making the Weston cell stable for a long time it is sometimes made up with 0.1N sulfuric acid (65). The emf is then 1.01825 international volt at 20°.

When the Weston cell is made up with acid the decrease in voltage =  $0.000\ 855 \times \text{normality of acid}$  (42).

#### TEMPERATURE COEFFICIENTS OF CELLS WITH DIFFERING AMOUNTS OF ACID

$$E = E_{20} + \alpha(t - 20) + \beta(t - 20)^2 \quad (42)$$

Acidity.....	0.078N	0.402N	0.566N	0.756N
$-10^\circ\alpha$ .....	42.5	43.6	43.7	45.5
$-10^\circ\beta$ .....	2.3	2.5	2.6	2.7

#### THE CONSTANCY OF ACID CELLS (42)

Emf at 20°C of the acid cell (standard: mean of 10 neutral cells, 1.01827 volt at 20°C)

Cell	Acidity: equivalents H <sub>2</sub> SO <sub>4</sub> per liter	Date of construction	July 23, 1919	July 29	Aug. 1	Oct. 8	Nov. 4	Mar. 9, 1920	Mar. 25	Oct. 8
218	0.078	1919 July 21	1.01+ 0.00840	1.01+ 0.00836	1.01+ 0.00830	1.01+ 0.00823	1.01+ 0.00822	1.01+ 0.00822	1.01+ 0.00822	1.01+ 0.00822
220	0.402	July 21	.00860	.00825	.00810	.00794	.00795	.00794	.00794	opened
221	0.566	July 21	.00807	.00802	.00783	.00781	.00780	.00781	.00780	.00780
222	0.756	July 21	.00777	.00782	.00772	.00763	.00763	.00761	.00762	.00763
223	0.756	July 21	.00732	.00738	.00733	.00761	.00763	.00761	.00763	.00761
226	0.402	July 25		.00818	.00809	.00797	.00798	.00794	.00795	.00794

**Effect of Composition of the Amalgam on the Emf of Weston Normal Cells.**— $v$ . (12, 60, 61).

#### RELATION BETWEEN THE EMF AND THE CONCENTRATION OF THE AMALGAM IN THE WESTON CELL (64)

The emf = 1.01823 international volt + the correction given in the table. The corrections are expressed in hundred-thousandths of a volt.

$t, ^\circ\text{C}$	Percentage of cadmium in the amalgam							
	1	2	3	4	5	6	7	8
0	-1197	-365	+35	34	35	35	36	36
5		-580	-32	35	36	36	37	37
10		-798	-246	29	29	30	30	30
15		-1024	-464	-79	17	17	18	18
20		-1250	-684	-291	-1	-1	0	0
25		-1483	-910	-507	-186	-24	-24	-23
30		-1717	-1132	-729	-407	-140	-50	-49
35		-1959	-1365	-954	-628	-362	-94	-80
40		-2202	-1594	-1184	-853	-583	-315	-114
45		-2446	-1837	-1415	-1081	-804	-539	-296

$t, ^\circ\text{C}$	Percentage of cadmium in the amalgam								
	9	10	10.5	11	11.5	12	12.5	13	13.5
0	36	36	37	37	39	40	41	47	50
5	37	37	38	38	40	41	42	48	51
10	30	30	31	31	33	34	34	35	38
15	18	18	19	19	21	22	22	25	27
20	0	0	1	1	3	4	4	4	7
25	-23	-23	-22	-22	-19	-18	-17	-17	-16
30	-49	-49	-48	-48	-44	-44	-43	-43	-42

$t, ^\circ\text{C}$	Percentage of cadmium in the amalgam								
	9	10	10.5	11	11.5	12	12.5	13	13.5
35	-79	-79	-78	-78	-77	-76	-76	-76	-75
40	-114	-112	-111	-112	-112	-112	-112	-111	-111
45	-148	-146	-145	-145	-146	-145	-145	-144	-144

In the amalgams containing 14 to 20% of cadmium the initial and final values are given for each temperature.

$t, ^\circ\text{C}$	Percentage of cadmium in the amalgam							
	14	14.5	15	16	17	18	19	20
0	+238	330	696	486	1098	1290	1560	1610
0	249	457	673	560	1101	1295	1564	1613
5	120	329	537	428	969	1162	1419	1476
5	123	339	533	431	969	1163	1420	1476
10	59	205	390	288	830	1022	1270	1332
10	61	215	387	292	830	1023	1270	1333
15	47	89	239	149	683	870	1124	1187
15	63	115	214	244	643	870	1075	1188
20	13	19	55	72	488	717	922	1036
20	13	19	55	70	488	716	922	1035
25	-15	-13	0	0	327	557	760	876
25	-15	-13	0	0	327	555	760	877
30	-42	-41	-31	-40	162	376	594	712
30	-42	-41	-32	-40	159	372	592	710
35	-74	-73	-71	-72	-6	204	423	539
35	-74	-73	-71	-72	-7	197	223*	539
40	-111	-110	-108	-109	-108	30	244	361
40	-111	-110	-109	-110	-108	24	241	360
45	-145	-144	-144	-144	-144	-120	+60	170
45	-145	-144	-143	-144	-144	-130	+48	169

\* Sic!



## ELECTROMOTIVE FORCE OF THE CELL:

Cd amalg. (10%) | CdSO<sub>4</sub>· $\frac{8}{3}$ H<sub>2</sub>O | Cd amalg. (dilute) (44, 45)

Percentage composition of the dilute amalgam	Emf at 29°C, volt	Temp. coeff., volt per °C
0.25	0.03420	+0.00051
0.50	0.02977 <sub>5</sub>	+0.00049
1.11	0.01945	+0.00045(?)
1.25	0.01612	+0.00046
1.7 $\frac{1}{2}$	0.01367	+0.00043
2.19	0.01083	+0.00043

Percentage composition of the dilute amalgam	Emf at 29°C, volt	Temp. coeff., volt per °C
2.83	0.00770	+0.00042
3.47	0.00511	+0.00042

Effect of Age on the Emf of the Weston Normal Cell (63).—Average change in 10 years: -0.000063 volt.

## THE WESTON UNSATURATED CELLS

The unsaturated Weston cell is made with a solution saturated at 4°C. It has an average voltage of 1.0187 international volt and a temperature coefficient of less than 0.00001 volt per °C (73). Each cell is accompanied by a certificate stating its voltage.

## UNSATURATED ACID WESTON CELLS

The measurements were made against three well-aged, very constant normal cells made at the National Physical Laboratory, Teddington, England. Their values were assumed to be such that the normal cells made for this investigation would have a value of 1.018054 volt at 25°C. The saturated solutions of cadmium sulfate were made with a 0.015 molal solution of sulfuric acid. The unsaturated solutions were made by adding the number of ml of this solution shown in the table to one liter of the saturated solution.

Composition of cadmium sulfate solutions, electromotive force, and temperature coefficients (71)

Solution number	Cells	Dilute acid added, ml	CdSO <sub>4</sub> , per cent	Emf at 25°C, volt	$\Delta E/\Delta T$ in mmv per deg			
					15-25°	25-35°	35-40°	40-45°
1	16-20	None	43.22 ± 0.01	1.018270 ± 0.0,8	2.8	2.7	5.0	8.1
2	41-45	2.5	43.12 ± 0.03	1.018374 ± 0.0,7	2.1	2.0	4.7	7.1
3	32-25	5	43.06 ± 0.00	1.018548 ± 0.0,5	1.0	1.1	3.4	5.9
4	26-30	9	43.94 ± 0.01	1.018711 ± 0.0,13	0.1	0.0	2.5	5.4
5	31-35	11	43.90 ± 0.01	1.018788 ± 0.0,7	-0.1	-0.3	2.1	4.5
6	36-40	15	42.77 ± 0.04	1.018983 ± 0.0,6	-1.3	-1.4	0.7	3.5
7	46-50	22.5	42.63 ± 0.00	1.019343 ± 0.0,7	-3.5	-3.6	-0.9	0.9
8	51-55	30	42.39 ± 0.01	1.019688 ± 0.0,14	-5.5	-5.5	-3.2	-0.6
9	56-60	50	41.84 ± 0.02	1.02095 ± 0.0,3	-13	-13	-10	-8

Neutral cells did not give consistent results for temperature coefficients.

## Cadmium Cells with Halide Electrolytes

Cells made in H-form. Measurements refer to an unsaturated Weston cell certified by the Reichsanstalt to have 1.0190 volt at room temperature (46).

1. Cells of the type: HgCd<sub>12.5</sub>% | CdX<sub>2</sub> satd. | Hg<sub>2</sub>X<sub>2</sub> paste | Hg

X	Electromotive force in volt
Cl	$E_t = 0.67180 - 0.000074(t - 18) - 0.0000015(t - 18)^2$
Br	$E_t = 0.55916 - 0.000366(t - 18) - 0.0000046(t - 18)^2$
I	$E_t = 0.41470 - 0.000362(t - 18) - 0.0000003(t - 18)^2$

2. Cells of the type: HgCd<sub>12.5</sub>% | CdX<sub>2</sub> soln. | Hg<sub>2</sub>X<sub>2</sub> paste | Hg

The emf of these cells can be represented by the formula

$$E_{18} = a \log N + b,$$

where  $N$  is the number of moles of CdX<sub>2</sub> per liter and  $a$  and  $b$  are constants:

X	a	b
Cl	-0.04306	0.7017
Br	-0.03953	0.58364
I	-0.03162	0.43338
$\frac{1}{2}$ SO <sub>4</sub>	-0.02501	1.05125

## The Clark Cell

HgZn<sub>10</sub>% | ZnSO<sub>4</sub>·XH<sub>2</sub>O satd. | Hg<sub>2</sub>SO<sub>4</sub> paste | Hg  
 $X = 7$  below 39°;  
 $= 6$  above 39°

Emf at 15°C = 1.4328 int. volt (1, 3, 24, 29, 75).

The Chicago International Electrical Congress of 1893 adopted

the value 1.434 international volt as the electromotive force of the Clark Cell at 15°C.

The Temperature Coefficient of the Clark Cell.— $E_t = E_{15} - 0.00119(t - 15) - 0.000007(t - 15)^2$  (31, 32).

Heat of the Reaction in the Clark Cell.—See (9, 51).

THE INFLUENCE OF PRESSURE ON THE EMF OF THE CLARK CELL (11, 13, 14, 15, 18)

$t, ^\circ\text{C}$	Emf at			
	1 atm.	500 atm.	1000 atm.	1500 atm.
First series				
25.0	1.41974	1.42608	1.43223	1.43820
30.0	1.41368	1.42019	1.42604	1.43168
35.0	1.40625	1.41290	1.41892	1.42452
38.0	1.40147	1.40812	1.41427	1.41987
39.5		1.40566	1.41183	1.41748
42.0			1.40772	1.41346
42.5				1.41255
45.0	1.39400	1.39938	1.40479	1.40983
50.0	1.38826	1.39387	1.39920	1.40436
55.0	1.38213	1.38800	1.39338	1.39854
Second series				
35.0	1.40625	1.41271	1.41880	1.42452
42.5				1.41255
45.0		1.39946	1.40479	1.40982
50.0	1.38820	1.39383	1.39910	1.40420
55.0	1.38210	1.38780	1.39314	1.39839

ZnSO<sub>4</sub>·7H<sub>2</sub>O

ZnSO<sub>4</sub>·6H<sub>2</sub>O

ZnSO<sub>4</sub>·7H<sub>2</sub>O

ZnSO<sub>4</sub>·6H<sub>2</sub>O



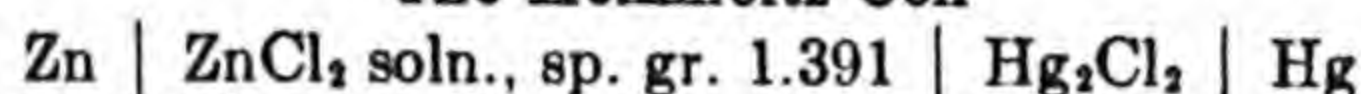
TEMPERATURE COEFFICIENT OF THE EMF  
For cells containing  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$

$P_{\text{atm.}}$		
1.....	$E_1 = 1.43701 - 0.0,221t - 0.0,188t^2$	
500.....	$E_{500} = 1.44105 - 0.0,840t - 0.0,206t^2$	
1000.....	$E_{1000} = 1.44993 - 0.0,263t - 0.0,178t^2$	
1500.....	$E_{1500} = 1.46025 - 0.0,528t - 0.0,140t^2$	

For cells containing  $\text{ZnSO}_4 \cdot 6\text{H}_2\text{O}$

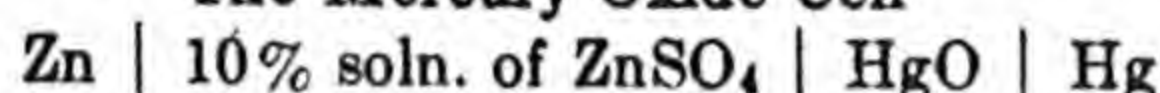
1.....	$E_1 = 1.42811 - 0.0,407t - 0.0,78t^2$
500.....	$E_{500} = 1.43277 - 0.0,418t - 0.0,72t^2$
1000.....	$E_{1000} = 1.44475 - 0.0,681t - 0.0,46t^2$
1500.....	$E_{1500} = 1.44331 - 0.0,429t - 0.0,70t^2$

The Helmholtz Cell



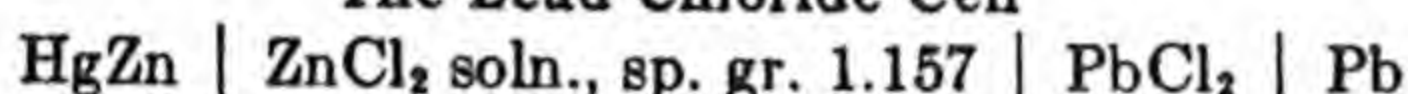
The reaction is:  $\text{Zn} + \text{Hg}_2\text{Cl}_2 = \text{ZnCl}_2 \text{ in soln.} + 2 \text{Hg}$ ;  $E_t = 1 + 0.000094(t - 15)$  volt (7, 27, 49).

The Mercury Oxide Cell



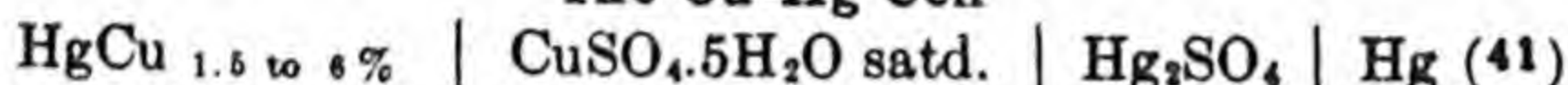
The reaction is probably:  $\text{Zn} + \text{HgO} = \text{ZnO} + \text{Hg}$ , which may be followed by secondary reactions;  $E_t = 1.390 - 0.0002(t - 12)$  (7, 22).

The Lead Chloride Cell



The reaction is:  $\text{Zn} + \text{PbCl}_2 = \text{ZnCl}_2 \text{ in solution} + \text{Pb}$ ;  $E = 0.5$  volt, temperature coefficient negligible (2).

The Cu-Hg Cell



$$E_t = 0.34979 - 0.000635(t - 20) - 0.0000024(t - 20)^2 \text{ volt}$$

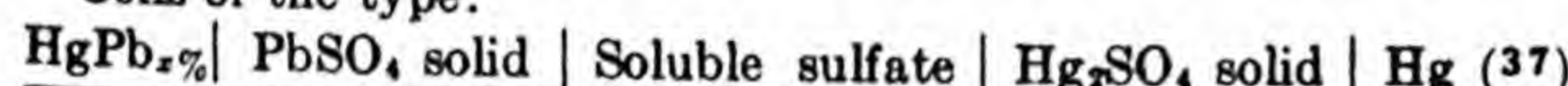
Total energy of the reaction from emf, 103.5 kJ; from thermochemical data, 103.0 kJ.

The same cell containing 10 to 12% copper in the amalgam,  $E_t = 0.3500 - 0.00064(t - 20) - 0.0000025(t - 20)^2$ .

Total energy change of the reaction from thermochemical data, 104.0; from emf, 104.15 kJ (47).

The Pb-Hg Cell

Cells of the type:



Soluble sulfate	$x, \%$	Observed emf, volt at 25°	Average variation of single cell, volt
$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}^*$	3.08 to 3.23	0.96466	0.00002
$\text{K}_2\text{SO}_4$	3.02	1.0300 to 1.0260	0.01
$\text{Li}_2\text{SO}_4 \cdot \text{H}_2\text{O}$	2.98	0.9615 to 0.9620	0.001
$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	2.84	0.9600 to 0.9610	0.001
$\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$	3.50	0.96466	0.00001
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	3.16	0.3489	0.0003
$\text{CdSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$	3.58	0.9520 to 0.9540	0.0012
$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	3.56	0.96480	0.00001
$\text{MnSO}_4 \cdot 5\text{H}_2\text{O}$	3.39	0.96478	0.00001

\* For other temperatures:  $E_t = E_{25} + 0.000174(t - 25) + 0.00000038(t - 25)^2$ . The total energy of the reaction is calculated to be 176.5 kJ from electromotive force; 175.0s from thermochemical data.

Low-Voltage Normal Cells (43)

				$E_{20^\circ}$ , volt
(a) $\text{HgCd}_{10\%}$	$\text{CdBr}_2 \cdot 4\text{H}_2\text{O}$	$\text{PbBr}_2$	$\text{HgPb}_{10\%}$	0.14506
(b) $\text{HgCd}_{10\%}$	$\text{CdCl}_2 \cdot 2\frac{1}{2}\text{H}_2\text{O}$	$\text{PbCl}_2$	$\text{HgPb}_{10\%}$	0.14186
(c) $\text{HgCd}_{10\%}$	$\text{CdI}_2$	$\text{PbI}_2$	$\text{HgPb}_{10\%}$	0.09835
(d) $\text{HgCd}_{10\%}$	$\text{CdSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$	$\text{PbSO}_4$	$\text{HgPb}_{10\%}$	0.08861
(e) $\text{Cd}$	$\text{CdSO}_4$		$\text{HgCd}_{10\%}$	0.05160
(f) $\text{Cd}$	$\text{CdI}_2$		$\text{HgCd}_{10\%}$	0.05156
(g) $\text{Cd}$	$\text{CdCl}_2$		$\text{HgCd}_{10\%}$	0.05135
(h) $\text{Cd}$	$\text{CdBr}_2$		$\text{HgCd}_{10\%}$	0.05012
(i) $\text{HgCd}_{10\%}$	$\text{CdSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$		$\text{HgCd}_{0.5\%}$	0.02980

Temperature coefficient:  $E_t = E_{20} + \alpha(t - 20) + \beta(t - 20)^2$ , volt.

Combination	$\alpha$	$\beta$
(a)	-0.000370	-0.000005
(b)	-0.000200	-0.000003
(c)	+0.000245	-0.000001
(d)	+0.000548	-0.000004
(e)	-0.000242	0
(f)	-0.000248	0
(g)	-0.000248	0
(h)	-0.000228	0
(i)	+0.00050	

Cells of the combinations (b) and (c) are most reproducible and are constant for a long period.

The LeClanché Dry Cell

Cells  $2.5 \times 6$  in. ( $63 \times 152$  mm) are designated as No. 6. Smaller cells are designated as follows (5)

Designation*	Diameter, inches	Height, inches	Diameter, mm	Height, mm
A.....	$\frac{5}{8}$	$1\frac{1}{2}$	16	48
B.....	$\frac{3}{4}$	$2\frac{1}{2}$	19	54
C.....	$1\frac{1}{8}$	$1\frac{1}{2}$	24	46
D.....	$1\frac{1}{4}$	$2\frac{1}{2}$	32	57
E.....	$1\frac{1}{2}$	$2\frac{1}{2}$	32	73
F.....	$1\frac{1}{2}$	$3\frac{1}{8}$	32	87

\* Includes flat cells of equivalent capacity.

The voltage requirements are those in the following table when measured with a voltmeter of not less than 100 ohm per volt, and having not less than 50 divisions of its scale per volt.

Designation	Nominal dimensions of cell		Minimum voltage
	Diameter, mm	Height, mm	
No. 6.....			1.50
F.....	32	87	1.50
E.....	32	73	1.50
D.....	32	57	1.50
C.....	24	46	1.49
B.....	19	54	1.48
A.....	16	48	1.47

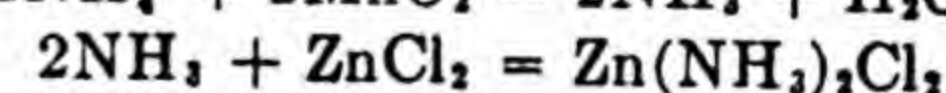
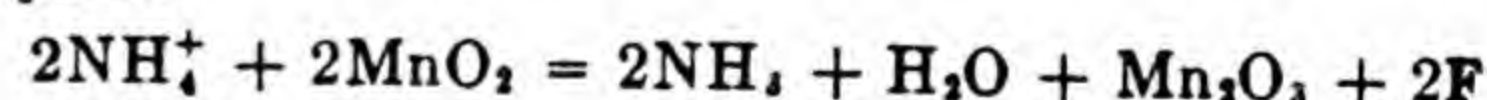
For additional data, v. (5).

The electromotive force of the manganese dioxide electrode of dry cells is determined by the hydrogen ion concentration, in the case of Caucasian, Brazilian, and domestic ores. For a ten-fold increase in hydrogen ion concentration the electrode potential increases from 0.06 to 0.08 volt. Chemically prepared dioxide is apparently free from this concentration effect (28).

Assumed Reactions of the LeClanché Cell

Negative pole:  $\text{Zn} + 2\text{F} + 2\text{Cl}^- = \text{ZnCl}_2$ .

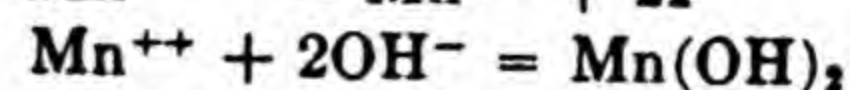
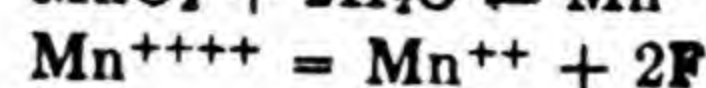
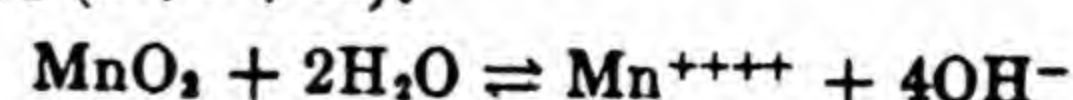
Positive pole:



Other oxides of manganese probably form.

Net reaction:  $\text{Zn} + 2\text{NH}_4\text{Cl} + 2\text{MnO}_2 = \text{Zn}(\text{NH}_3)_2\text{Cl}_2 + \text{Mn}_2\text{O}_3 + \text{H}_2\text{O}$ .

The reaction at the positive pole may also be considered to take place as follows (20, 36, 68):



Net reaction:  $\text{MnO}_2 + 2\text{H}_2\text{O} = \text{Mn}(\text{OH})_2 + 2\text{OH}^- + 2\text{F}$ .



## EFFECTS OF TEMPERATURE ON DRY CELLS (4)

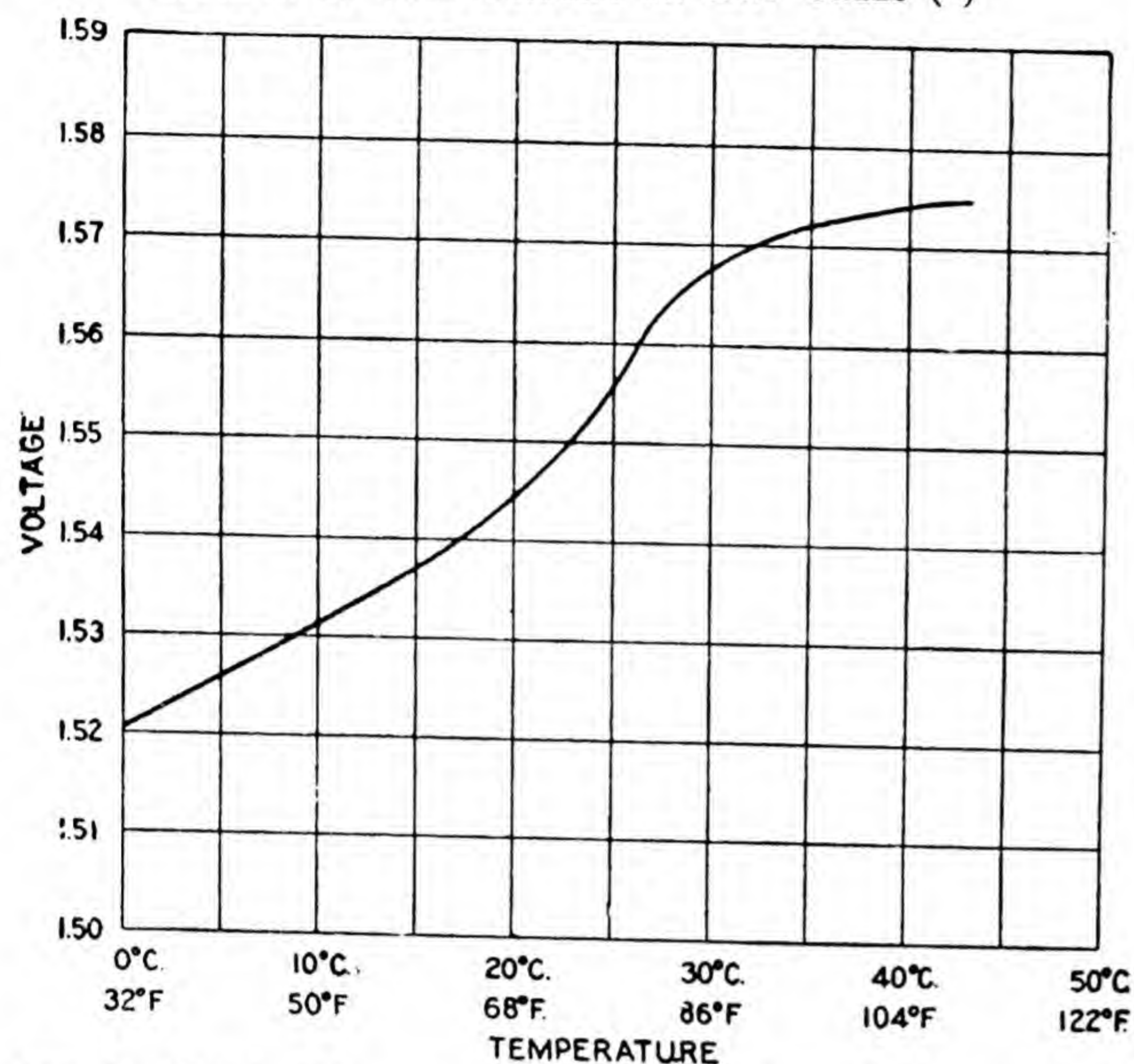


FIG. 1.—Effect of temperature on open-circuit voltage of dry cells.

Mean of measurements on 16 cells, No. 6 size, paper-lined construction, including four different brands. The cells were kept at fixed temperatures 24 hours before being measured.

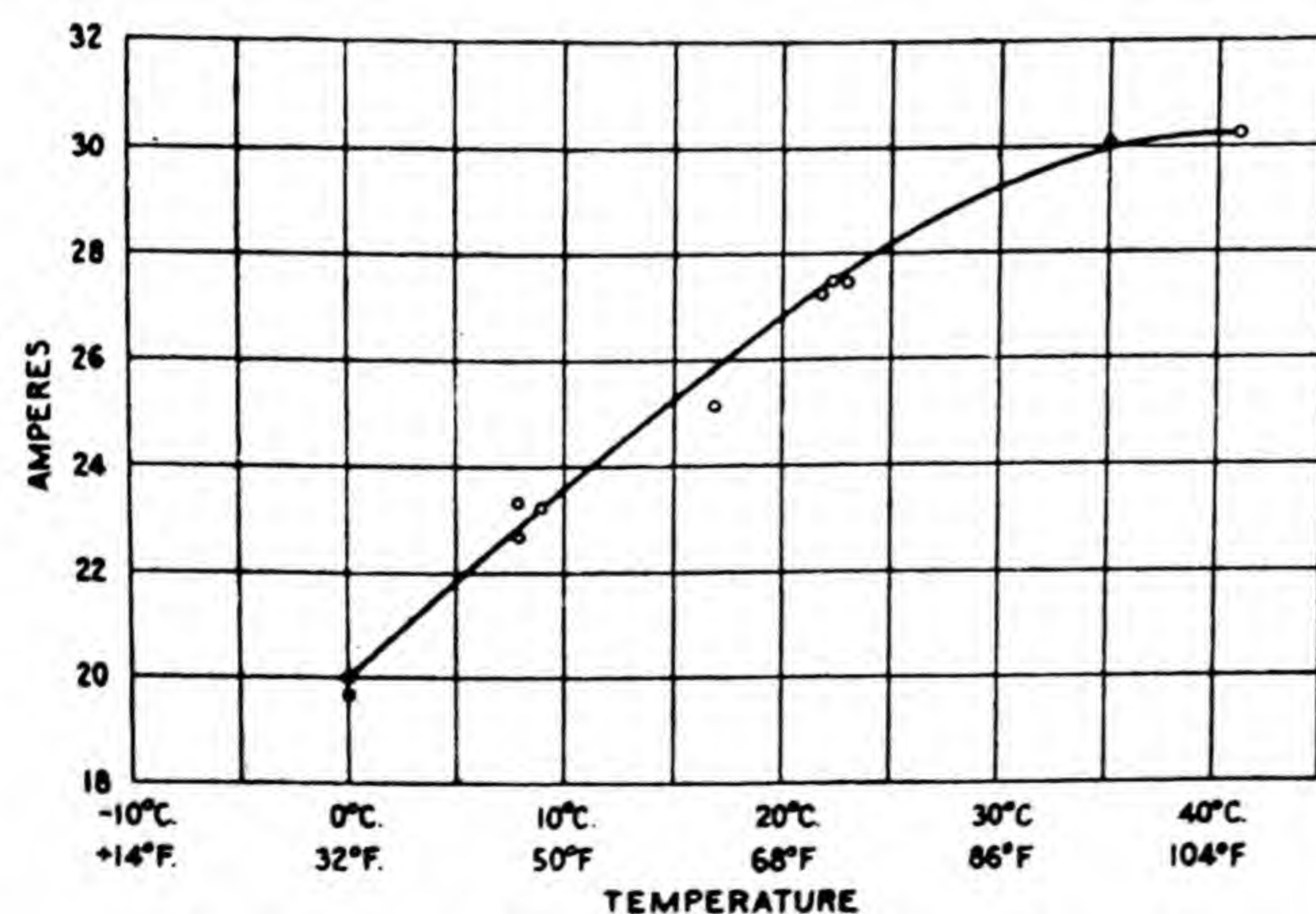


FIG. 2.—Effect of temperature on short-circuit current.

Mean values for a group of six cells maintained at each of the temperatures indicated for at least 24 hours prior to the measurements. The temperatures were taken in the following order; 22, 0, 22.5, 8, 0, 21.8, 35, 41, 8, 16.8, and 9°C.

## EFFECT OF TEMPERATURE ON THE SHORT-CIRCUIT CURRENT OF DRY CELLS STORED FOR 10 WEEKS ON OPEN CIRCUIT (PRITZ (53))

Temperature of storage, °C	Percentage decrease in short-circuit current at end of 10 weeks	Temperature of storage, °C	Percentage decrease in short-circuit current at end of 10 weeks
5	4.4	55	52.0
25	10.0	65	71.0
35	19.0	75	98.0
45	25.0		

Recent experiments show that the measurements of Pritz for cells stored at 25°C are approximately correct for dry cells when new, but the rate of decrease of short-circuit current becomes less as the age of the cell increases; the total decreases during a year at room temperature being about 25%.

## HOURS OF SERVICE OF NO. 6 DRY CELLS DISCHARGED TO 0.5 VOLT AT VARIOUS RATES AND TEMPERATURES (48, 53)

Temp., °C	Service at various resistances of external circuit in ohms			
	2 ohm, hr	4 ohm, hr	8 ohm, hr	16 ohm, hr
0	40	80	270	560
25	60	94	280	700
50	70	160	350	650
75	65	158	315	615

## HOURS OF SERVICE OF DRY CELLS, NO. 6 SIZE, DISCHARGED TO 0.6 VOLT AT FIXED RATES OF CURRENT AND AT VARIOUS TEMPERATURES

Average of results of tests made on three standard makes of dry cells of paper-lined construction

Temp., °C	Service at various rates of discharge in ampere				
	0.1 amp., hr	0.25 amp., hr	0.50 amp., hr	0.75 amp., hr	1.00 amp., hr
0	136	40	14	7	5
25	220	64	24	13	9
40	300	94	31	18	11

## INITIAL WORKING VOLTAGE OF NO. 6 DRY CELL (21)

Ohm resistance of circuit	Corresponding ampere drain	Initial working voltage	Ohm resistance of circuit	Corresponding ampere drain	Initial working voltage
0.00	42.9*	0.00*	4	0.370	1.48
.01	32.0*	.32*	8	.185	1.48
.02	26.5*	.53*	16	.092	1.48
.04	18.5*	.74*	32	.046	1.48
.08	12.0*	.96*	64	.023	1.49
$\frac{1}{8}$	8.8	1.10	128	.0117	1.50
$\frac{1}{4}$	5.1	1.28	256	.0059	1.52
$\frac{1}{2}$	2.76	1.38	512	.0030	1.52
1	1.45	1.45	$\infty$	.0000	1.53
2	0.735	1.47			

\* Estimated by extrapolation.



## LeClanché Dry Cell.—(Continued)

HOURS OF SERVICE FOR NO. 6 PAPER-LINED DRY CELL AT ROOM TEMPERATURE, THROUGH CONSTANT RESISTANCE (21)

Figures in parentheses are interpolated

Cell discharged	Cut-off voltage	Total life in hours for various ohms resistance of circuit, ohm														
		$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	16	32	64	128	256	512	1024	1792
Continuously (1).....	1.2		0.02	0.13	0.70	2.2	9.1	47	115	390	1 050	2 780	4 220	6 350	7 850	9 120
	1.0	0.01	.21	.95	3.7	11.1	32.5	89	233	650	1 560	3 200	4 800	6 850	9 720	10 740
	0.8	.14	.76	2.3	7.4	20.7	53.0	119	304	740	1 750	3 350	5 100	7 300	10 200	11 500
	.6	.50	1.9	5.1	12.5	36.3	75.0	184	383	805	2 470	3 500	5 220	7 550	10 570	11 800
	.4	1.4	3.8	8.5	21.4	49.8	100.0	227	462	890	2 530	3 650	5 350	7 700	10 970	12 100
30 minutes every hour (2).....	1.2				1.0	4.0	15.0	40	210	550	1 370					
	1.0			(1.1)	5.5	13.0	37.0	120	320	810	1 570					
	0.8	(0.2)	(0.8)	(3.0)	9.0	26.0	61.0	190	375	920	1 630					
	.6	(0.7)	(2.0)	(5.6)	15.5	43.0	87.0	230	420	1 000	1 680					
	.4	(1.5)	(4.0)	(9.7)	25.0	58.0	120.0	280	470	1 040	1 750					
15 minutes every hour (3).....	1.2				1.0	5.0	13.0	90	240	580	1 225					
	1.0		0.17	1.2	5.0	17.0	47.0	157	370	815	1 275					
	0.8	0.31	1.0	3.0	10.5	40.0	80.0	195	445	875	1 325					
	.6	.91	2.3	5.1	16.5	74.0	100.0	223	500	920	1 370					
	.4	2.0	4.3	11.0	29.0	89.0	122.0	264	560	965	1 420					
5 minutes every hour (4).....	1.2			0.18	2.5	10.5	45.0	115	292	508						
	1.0		0.34	2.0	7.5	28.0	75.0	166	360	542						
	0.8	0.21	1.2	4.1	13.5	40.0	93.0	201	385	567						
	.6	.75	2.3	6.4	20.0	50.0	114.0	224	403	602						
	.4	1.9	4.3	11.0	33.0	62.0	128.0	236	416	625						
2 minutes every hour (5).....	1.2			0.53	3.5	22.0	56.0	152	207	272						
	1.0	0.06	0.53	2.3	13.0	35.0	78.0	167	216	288						
	0.8	.28	1.3	5.4	19.5	44.0	90.0	194	224	307						
	.6	.72	3.0	10.0	28.0	59.0	103.0	209	231	333						
	.4	1.8	6.0	15.0	36.0	68.0	109.0	217	240							
$\frac{1}{2}$ minute every hour (6).....	1.2			2.0	8.7	22.0	42.0	70								
	1.0		1.6	6.0	15.7	29.0	46.0	76								
	0.8	0.80	3.7	8.5	17.7	31.0	48.0	80								
	.6	1.9	6.5	12.0	20.0	33.0	50.0	82								
	.4	5.2	10.3	16.0	23.0	36.0	52.0	85								
5 minutes every 10 minutes (7).....	1.2			0.14	1.5	5.0	20.0	40	220	530	1 280	2 550				
	1.0		0.42	1.3	6.0	14.5	45.0	115	340	795	1 580	2 800				
	0.8	0.45	1.5	3.3	9.5	28.0	70.0	170	410	930	1 670	2 850				
	.6	1.3	3.0	6.0	16.5	45.0	105.0	220	460	1 010	1 730	2 875				
	.4	2.3	4.8	9.6	26.0	60.0	135.0	270	520	1 100	1 810	3 000				
30 minutes every 6 hours (8).....	1.2				1.3	15.0	40.0	107	309	460						
	1.0				9.5	29.0	75.0	137	353	505						
	0.8				17.0	40.0	93.0	186	367	545						
	.6				24.0	48.0	102.0	216	381	590						
	.4				30.0	56.0	111.0	228	395	625						
5 minutes every 6 hours (9).....	1.2			0.2	4.1	17.0	56.0									
	1.0		0.24	2.9	11.2	32.0	61.0									
	0.8	0.34	1.7	6.7	16.3	37.0	63.0									
	.6	.9	3.5	10.2	21.0	42.0	65.0									
	.4	2.8	6.5	14.0	26.0	47.0	82.0									

## The Féry Zinc-Carbon Cell

Similar to the LeClanché but contains no manganese dioxide. The carbon electrode is cylindrical and is made of specially prepared carbon. A horizontal plate of zinc is at the bottom of the carbon cylinder and is insulated from it. A test cell mounted in a vessel 10 cm square and 22 cm high, containing 1 liter of water + 12 of ammonium chloride and a zinc plate weighing 160 g yield 25 ampere hours (69).

## Caustic Soda Cells

## REACTIONS OF THE CAUSTIC SODA CELL (20)

Negative pole:  $\text{Zn} + 2\text{F} + \text{NaOH} + 2\text{OH}^- = \text{NaHZnO}_2 + \text{H}_2\text{O}$ .

Positive pole:  $2\text{H}^+ + 2\text{CuO} = \text{H}_2\text{O} + \text{Cu}_2\text{O} + 2\text{F}$  (also:  $\text{Cu}_2\text{O} + 2\text{H}^+ = \text{H}_2\text{O} + 2\text{Cu} + 2\text{F}$ ).

Net reaction:  $\text{Zn} + 2\text{CuO} + \text{NaOH} = \text{NaHZnO}_2 + \text{Cu}_2\text{O}$ .

The following graphs show performance under different conditions of temperature and concentration of electrolyte (36.1).



## Caustic Soda Cells.—(Continued)

CuO | 20 to 25% solution of NaOH covered with oil | Zn amalg.  
This cell is made in capacities from 200 to 1000 ampere hours.

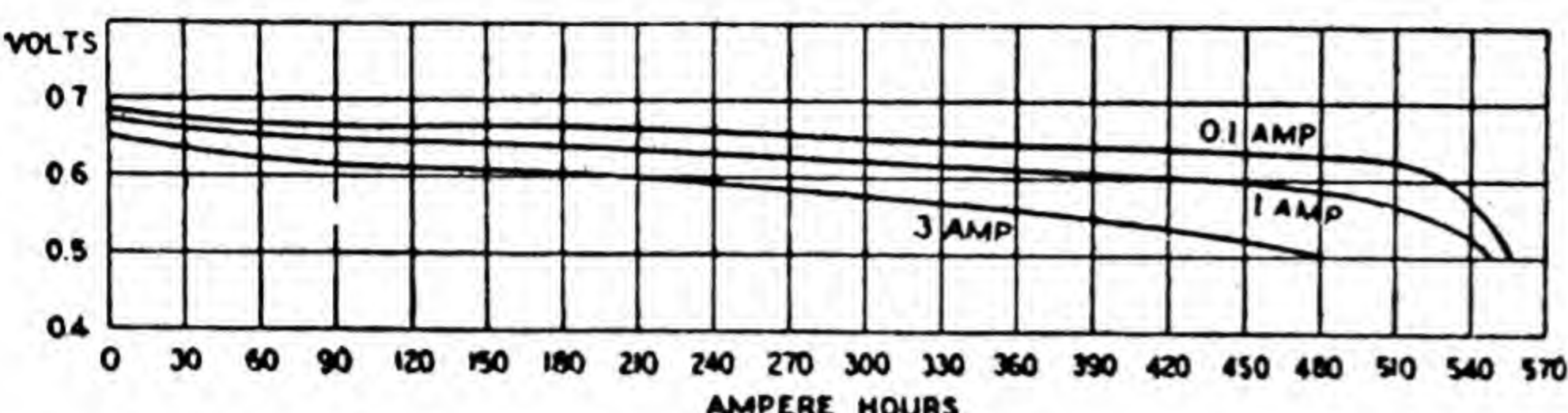


FIG. 3.—Graphs showing the voltage of a 500-ampere hour cell during discharge at 23°C. (Private Communication.)

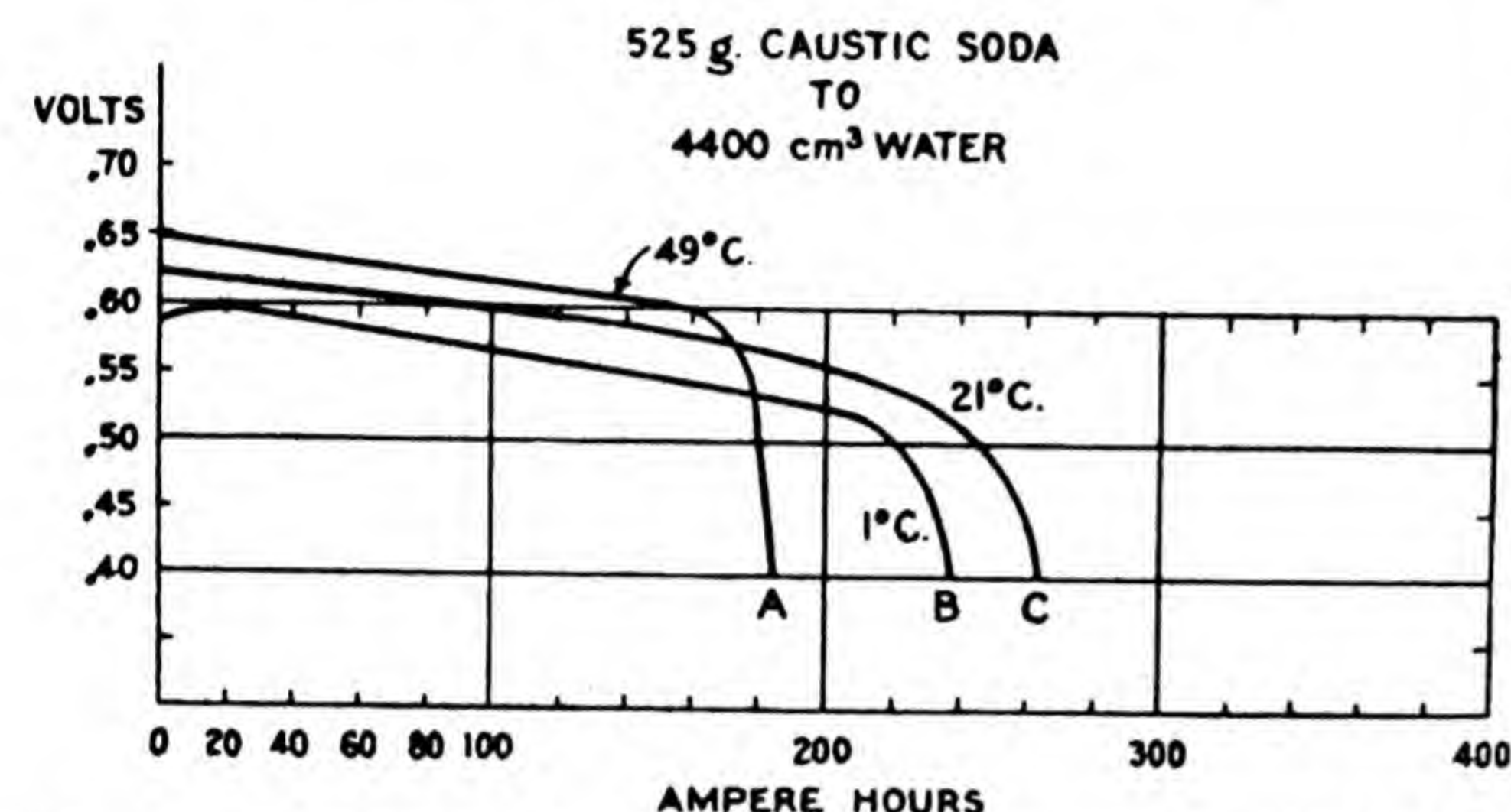


FIG. 4.—Performance of cell containing 525 g caustic soda to 4400 cm³ water. Current constant at 3 ampere.

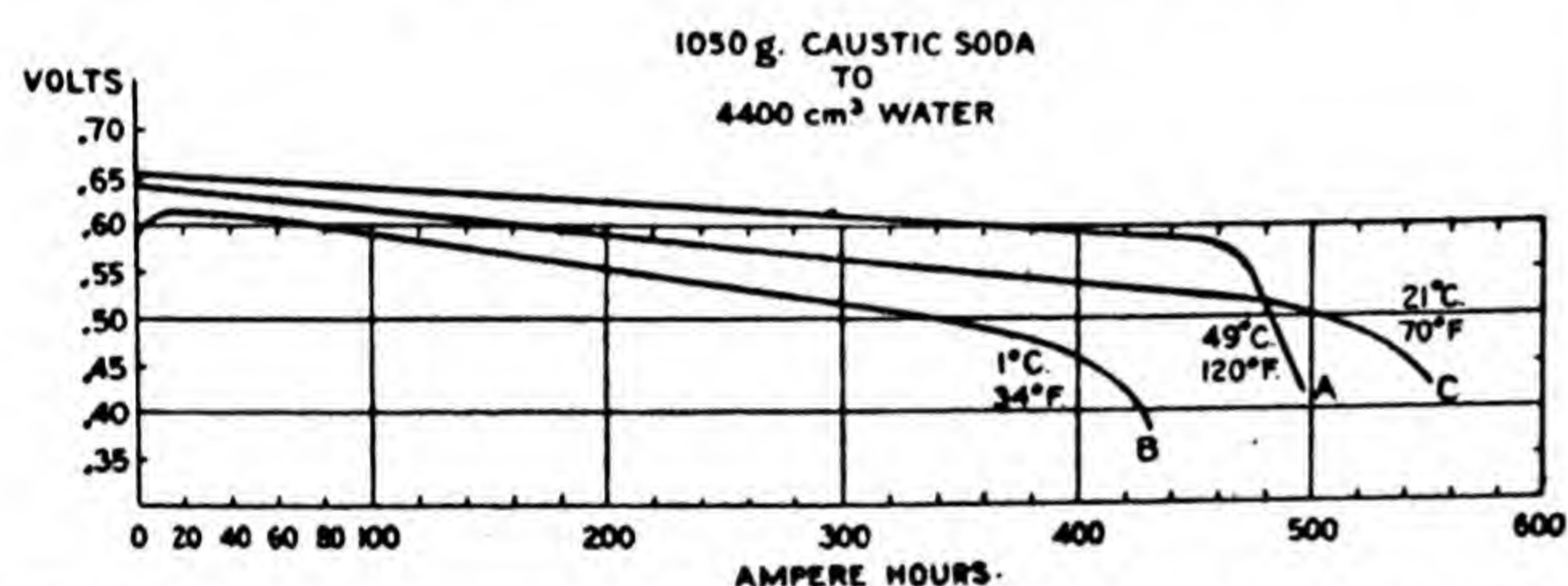


FIG. 5.—Performance of cell containing 1050 g caustic soda to 4400 cm³ water, the normal concentration. Current constant at 3 ampere.

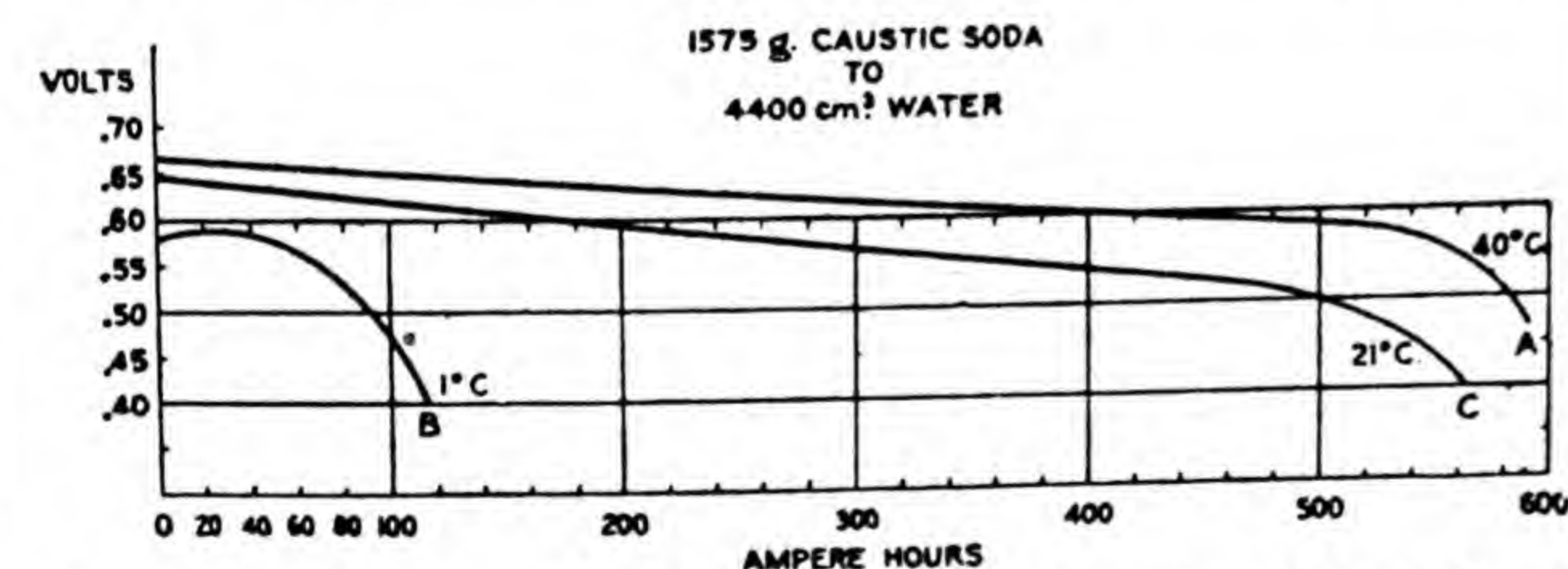


FIG. 6.—Performance of cell containing 1575 g caustic soda to 4400 cm³ water. Current constant at 3 ampere.

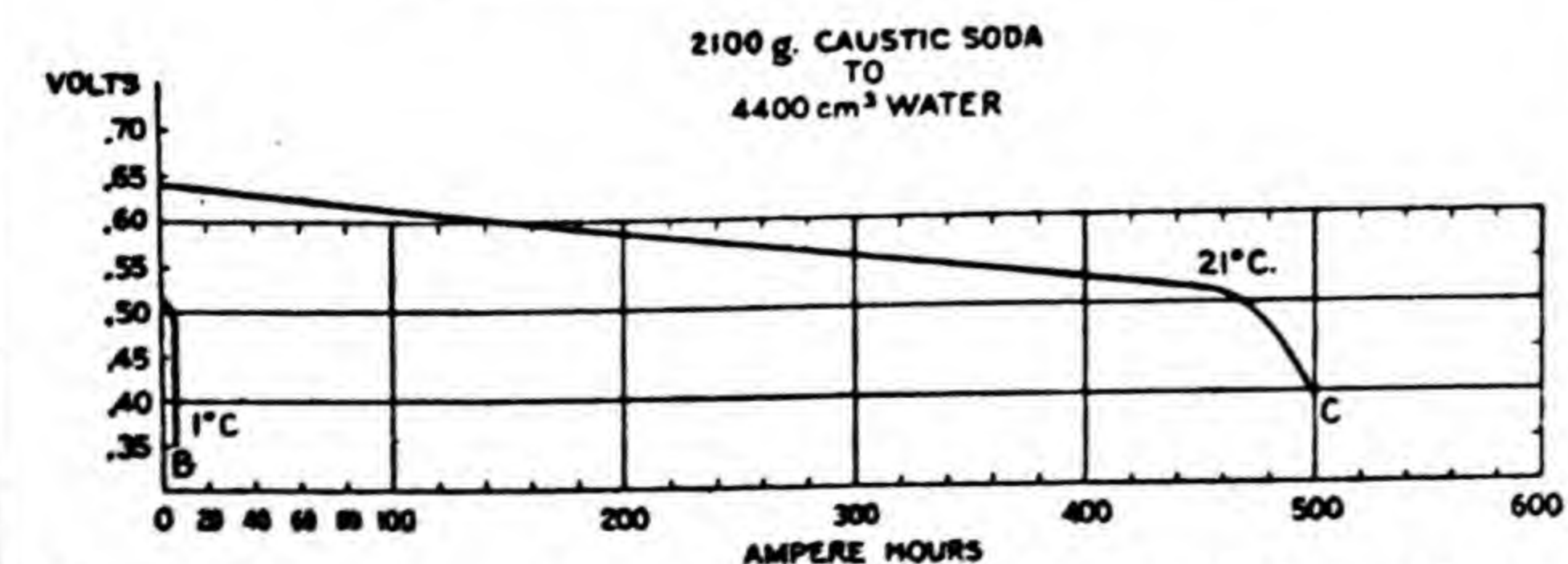


FIG. 7.—Performance of cell containing 2100 g caustic soda to 4400 cm³ water. Current constant at 3 ampere.

The Nyberg cell: Amalgamated Zn | 10% NaOH | Porous C  
Voltage 1.00 to 1.18 for currents of 1 to 0.1 ampere. For a volume of 1000 cm³ and weight 1300 g the maximum capacity is 210 watt-hr (38).

## The Daniell Cell

Zn | ZnSO₄ or H₂SO₄ soln. | CuSO₄ soln. | Cu

The two electrolytes are separated by a porous cup, or by difference in density in the "gravity" type of cell.  $E$  varies from 1.07 to 1.14 volt.

The reaction is:  $\text{Zn} + \text{CuSO}_4 \text{ in solution} = \text{ZnSO}_4 \text{ in solution} + \text{Cu}$  (16).

## The Grove and Bunsen Cells

HgZn | 1 vol. H₂SO₄ to 12H₂O | Conc. HNO₃ | Pt

$E = 1.9$  to 2 volt. The two acids are separated by a porous cup.

The Bunsen cell is the Grove cell with platinum replaced by carbon.

## The Poggendorff Cell

HgZn | Dil. H₂SO₄ | Conc. soln. of Na₂Cr₂O₇ or K₂Cr₂O₇ | C  
+ H₂SO₄

Reaction at negative pole:  $3\text{Zn} + 6\text{F} + 3\text{SO}_4^{--} = 3\text{ZnSO}_4$  which is the same for all cells with zinc dipping into sulfuric acid.

At the positive pole:  $\text{Na}_2\text{Cr}_2\text{O}_7 + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + \text{H}_2\text{O} + 2\text{CrO}_3$ .

$2\text{CrO}_3 + 3\text{H}_2\text{SO}_4 + 6\text{H}^+ = 6\text{H}_2\text{O} + \text{Cr}_2(\text{SO}_4)_3 + 6\text{F}$

Net reaction:  $3\text{Zn} + 7\text{H}_2\text{SO}_4 + \text{Na}_2\text{Cr}_2\text{O}_7 = 3\text{ZnSO}_4 + \text{Na}_2\text{SO}_4 + \text{Cr}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O}$ .

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(For a key to the periodicals see end of volume)

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## THE POTENTIALS OF ELECTRODE CELLS

CHARLES P. SMYTH

The term "electrode cell" as employed in this section signifies a cell whose emf is determined solely or chiefly by differences in concentration or physical condition of some atomic or molecular species in the electrode. The cells are arranged in alphabetical order of the symbols of the most important chemical element of the cell. In most instances the cell is given by literature reference only and only reversible cells have been included.

Le terme "electrode cell" tel qu'il est employé dans cette section, signifie une cellule dont la fem est déterminée uniquement ou principalement par les différences de concentration ou de conditions physiques d'une espèce atomique ou moléculaire, dans l'électrode. Les cellules sont arrangées dans l'ordre alphabétique des symboles de l'élément chimique le plus important de la cellule. Dans la plupart des cas, la cellule n'est donnée que par une référence bibliographique et les cellules réversibles ont seules été mentionnées.

Der Ausdruck "electrode cell," wie er in diesem Abschnitt verwendet wird, bezeichnet eine Zelle deren elektromotorische Kraft ausschliesslich oder hauptsächlich durch die Differenz in den Konzentrationen oder in den physikalischen Zustand einiger atomarer oder molekularer Stoffe in der Elektrode bestimmt ist. Die Zellen sind in alphabetischer Reihenfolge der Symbole des wichtigsten Elementes der Zelle, angeordnet. In vielen Fällen ist die Zelle nur durch die Literaturstelle angegeben und es werden nur reversible in Betracht gezogen.

Il termine "electrode cell" come viene impiegato in questo capitolo significa una cella la cui fem è determinata in modo esclusivo, o per la massima parte, da differenze di concentrazione o di condizione fisica di qualche specie molecolare o atomica nell'elettrodo. Le celle sono disposte in ordine alfabetico del simbolo dell'elemento più importante delle celle stesse. Nella maggior parte dei casi la cella è indicata con la citazione bibliografica, e solo le celle reversibili sono state incluse.

ABBREVIATIONS		ABRÉVIATIONS	
Ac	Acetate radical.	Ac	Radical acétate.
$E_t$	Emf at $t$ , °C.	$E_t$	Fem à $t$ , °C.
mv	Millivolts.	mv	Millivolts.
$M$	Molal.	$M$	Molal.
$M_x$	The element M in the amount $x$ wt. % in the electrode.	$M_x$	L'élément M dans la proportion $x$ % poids dans l'électrode.
$N$	Normal.	$N$	Normal.
satd.	Saturated.	satd.	Saturé.

## AQUEOUS SOLUTIONS

## Ag

Ag | AgCl | 0.1N KCl | HgCl | Hg +  
 $E_{25} = 45.1 \pm 0.5$  mv;  $10^3 dE/dP = (2.66 \pm 0.2)$  mv/atm. (99)

Ag(colloidal) | AgNO<sub>3</sub> | Ag(cryst.) +  
 $E_{25} = 25 \pm 5$  mv (92)

Ag(powder) | 0.1N AgNO<sub>3</sub> | Ag(compact) (62)

Ag<sub>2</sub>Pd | Ag<sub>2</sub>SO<sub>4</sub> | Ag (61)

Ag<sub>2</sub>Se or Te |  $N/7$  AgNO<sub>3</sub> | Ag (68)

Ag<sub>2</sub>Se | AgNO<sub>3</sub>(satd.) | Ag (64)

## Au

Au(var. treatments) | AuCl<sub>3</sub> | KCl | HgCl | Hg (28)

Au<sub>2</sub>Sn | SnCl<sub>4</sub> | AuCl<sub>3</sub> | Au (54)

## Ba

Ba<sub>2</sub>Hg | Ba(OH)<sub>2</sub>(satd.) | KCl |  $N$  KCl | HgCl | Hg (90)

## Bi

Bi<sub>2</sub>( $x = 1.6$  to  $93.9$  at. %)Hg | Bi(NO<sub>3</sub>)<sub>3</sub> | Bi (66, 67)

## Cd

Cd<sub>2</sub>Ag |  $N$  CdSO<sub>4</sub> | Cd (51, 90.5)

Cd<sub>2</sub>Au |  $N$  CdSO<sub>4</sub> | Cd (88)

Cd<sub>2</sub>Bi |  $N$  CdSO<sub>4</sub> | Cd (29, 35)

Cd<sub>2</sub>Bi<sub>2</sub>Pb |  $N$  CdSO<sub>4</sub> | Cd (48)

Cd<sub>2</sub>Cu |  $N$  CdSO<sub>4</sub>,  $N$  H<sub>2</sub>SO<sub>4</sub> | Cd (68)

Cd<sub>2</sub>Hg | CdSO<sub>4</sub> | Cd<sub>2</sub>Hg

Precise determinations of  $E$  and  $dE/dt$  for a number of dilute amalgams (80, 81); cf. (9, 16, 38)

Cd<sub>2</sub>Hg | CdSO<sub>4</sub>. $\frac{2}{3}$ H<sub>2</sub>O, Hg<sub>2</sub>SO<sub>4</sub> | Hg (93)

v. p. 312

Cd<sub>2</sub>Hg | CdSO<sub>4</sub>. $\frac{2}{3}$ H<sub>2</sub>O | Cd<sub>2</sub>Hg

v. p. 312

## ABKÜRZUNGEN

Ac	Acetat-Radikal.
$E_t$	Elektromotorische Kraft bei $t$ , °C.
mv	Millivolt.
$M$	Molar.
$M_x$	Das Element M ist zu $x$ Gew. % in der Elektrode vorhanden.
$N$	Normal.
satd.	Gesättigt.

## ABBREVIAZIONI

Ac	Radicale acetico.
$E_t$	Fem a $t$ , °C.
mv	Millivolts.
$M$	Molare.
$M_x$	L'elemento M nella quantità $x$ in peso % nell'elettrodo.
$N$	Normale.
satd.	Saturo.

Cd<sub>2</sub>Hg |  $N$  CdSO<sub>4</sub> | Cd (v. p. 312)

Cd<sub>2</sub>Hg | CdSO<sub>4</sub> | Cd <sub>$\alpha$</sub> ,  $\beta$  or  $\gamma$  (14, 15)

Cd<sub>2</sub>Pb |  $N$  CdSO<sub>4</sub> | Cd (29, 35)

Cd<sub>2</sub>Sb | CdSO<sub>4</sub> | Cd (44)

Cd<sub>2</sub>Sn | CdSO<sub>4</sub> | Cd (29, 35)

Cd<sub>2</sub>Tl |  $M$  CdSO<sub>4</sub> or TlCl(satd.) | Tl<sub>2</sub>Hg (50)

## Ce

Ce<sub>2</sub>Fe | 0.3N CeCl<sub>3</sub>, 0.2N FeSO<sub>4</sub> |  $N$  KCl | HgCl | Hg (10)

Ce<sub>2</sub>Fe | 0.3N CeCl<sub>3</sub>, 0.2N ZnCl<sub>2</sub> |  $N$  KCl | HgCl | Hg (10)

## Co

Co<sub>2</sub>M |  $N$  CoSO<sub>4</sub> | Co (20, 21, 22, 23, 24, 26)

$M = \text{Ag, As, Bi, Cu, Pb, Sb}$

## Cu

Cu<sub>2</sub>Ag |  $N$  CuSO<sub>4</sub> | Cu (35)

Cu<sub>2</sub>Au | 0.5M[CuSO<sub>4</sub> or Cu(NO<sub>3</sub>)<sub>2</sub>] | Cu (95)

Cu<sub>2</sub>Hg | CuSO<sub>4</sub> | Cu<sub>2</sub>Hg (82, 83)

Cu<sub>2</sub>( $x = 1$  to  $16\%$ )Hg | CuSO<sub>4</sub>(satd.), Hg<sub>2</sub>SO<sub>4</sub> | Hg +  
 $E_{25} = 347.2 \pm 0.2$  mv (11)

+Cu<sub>12</sub>% Hg | CuSO<sub>4</sub>(dil.) | Cu

$E$  (mv  $\pm 1$ ) = 6.5 at 0°; = 5.5 at 25° (11)

Cu<sub>2</sub>P |  $N$  CuSO<sub>4</sub> | Cu (37)

Cu<sub>2</sub>Pd | 0.5M CuSO<sub>4</sub> | Cu (61)

Cu<sub>2</sub>Se | CuSO<sub>4</sub> | Cu (64)

Cu<sub>2</sub>Te |  $N$  CuSO<sub>4</sub> | Cu (68)

## Fe

Fe(var. treatments) | FeSO<sub>4</sub> |  $N$  KCl, HgCl | Hg

Other similar cells (1, 28, 76, 77). A magnetic field has a negligible effect upon the potential of Fe, but lowers the potential of hydrogen occluded in Fe, the amount of the lowering being approximately proportional to the intensity of the magnetic field and to the amount of the hydrogen overvoltage (84); cf. (74, 103).



**H<sub>2</sub>**  
H<sub>2</sub>(p) | 0.1N HCl | HgCl | Hg+ (33)

<i>p</i> <sub>atm.</sub>	<i>E</i> (mv)	<i>p</i> <sub>atm.</sub>	<i>E</i> (mv)	<i>p</i> <sub>atm.</sub>	<i>E</i> (mv)
1.0	399.0	439.3	480.4	754.4	490.3
37.9	445.6	556.8	484.4	862.2	493.2
51.6	449.6	568.8	485.0	893.9	493.8
110.2	459.6	701.8	489.1	974.5	496.3
204.7	468.3	717.8	489.9	1035.2	497.5
386.6	478.4	731.8	489.3		

**In**

In<sub>2</sub>Hg | In<sub>2</sub>(SO<sub>4</sub>)<sub>2</sub> | In<sub>2</sub>Hg

Dilute amalgams; *E* ± 0.005 mv at 0 and 30° (86, 87)

**Na**

Na<sub>2</sub>Hg | 0.5N NaOH | Na<sub>2</sub>Hg

Dilute amalgams; values of *E*<sub>25</sub> ± 0.08 mv and of *dE/dt* (78)

**Ni**

Ni<sub>2</sub>Cu | N NiSO<sub>4</sub> | Ni (100)

Ni<sub>2</sub>Cu | *y*N NiSO<sub>4</sub> + (1 - *y*)N CuSO<sub>4</sub> | N KCl | HgCl | Hg (31)

**Pb**

Pb<sub>2</sub>M | N Pb(NO<sub>3</sub>)<sub>2</sub> | Pb

M = Ag, As, Bi, Cu, Hg, Pd, Pt, Sb, Te (66, 67, 68, 70, 71, 72, 73)

Pb<sub>2</sub>Bi | PbCl<sub>2</sub>(satd.) | Pb

Dilute and concentrated alloys; *E* ± 0.2 mv at room temp. (91)

Pb<sub>2</sub>Hg | PbAc<sub>2</sub>, HAc | Pb<sub>2</sub>Hg

Dilute amalgams; *E* ± 0.01 mv at 0 and 30° (82, 83)

Pb<sub>2</sub>Hg | PbCl<sub>2</sub> | 0.5N NaCl, 0.5N HCl | HgCl | Hg

*E* ± 0.1 mv at 0.2, 15.5 and 29.2° (2)

+Pb<sub>30</sub>% Hg | M? [PbAc<sub>2</sub> or Pb(ClO<sub>4</sub>)<sub>2</sub>] | Pb

*E*<sub>25</sub> = 5.7 ± 0.1 mv; *dE/dt* = 0.02 mv/°C (30)

Pb<sub>2</sub>Hg | PbCl<sub>2</sub>(satd.) | HgCl | Hg+ (I)

+Pb<sub>2</sub>Hg | PbCl<sub>2</sub>(satd.) | Pb (II)

+Pb<sub>10</sub>% Hg | PbCl<sub>2</sub>(satd.) | Pb<sub>30</sub>% Hg (III)

<i>x</i> , %	Type	°C	<i>E</i> , mv	±	10 <sup>3</sup> <i>dE/dP</i> , mv/atm.
30	I	15	529.85	0.2	3.96 ± 0.16
30	I	25	530.62	0.2	3.90 ± 0.16
1	I	25	525.6	0.1	2.98 ± 0.2
30	II	25	24.2	1	1.0 ± 0.2
	III	25	7.5	0.5	0.72 ± 0.1

Pb<sub>2</sub>Se | Pb(NO<sub>3</sub>)<sub>2</sub>(satd.) | Pb

Also with PbCl<sub>2</sub>(satd.) (64)

**Sb**

Sb(expl.) | SbCl<sub>3</sub> | Sb(ord.) +

*E*<sub>15</sub> = 18 ± 1 mv (18)

Sb<sub>2</sub>Cu | SbCl<sub>3</sub>, HCl | Sb (3)

Sb<sub>2</sub>Se | 0.1N SbCl<sub>3</sub>, 2N HCl | Sb (73)

Sb<sub>2</sub>Se | SbCl<sub>3</sub>, HCl | Sb

Effect of light on Sb<sub>2</sub>Se (63, 65)

**Sn**

Sn(gray) | (NH<sub>4</sub>)<sub>2</sub>SnCl<sub>6</sub> | Sn(white) (12)

Sn<sub>2</sub>Ag | SnCl<sub>2</sub>(satd.) | Sn (35)

MSn<sub>2</sub> | N H<sub>2</sub>SO<sub>4</sub> or KOH | Sn

M = Ag, As, Au, Bi, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Te, or Cu + Ag (68, 69, 70)

Sn<sub>2</sub>Bi | SnCl<sub>2</sub> | Sn (91)

Sn<sub>2</sub>Co | N CoSO<sub>4</sub> | Co (25)

Sn<sub>2</sub>Hg | 0.5N SnCl<sub>2</sub> | Sn<sub>2</sub>Hg

0 and 30°; *E* ± 0.005 mv (86, 87); cf. (36)

Sn<sub>2</sub>Ni or Sb | SnCl<sub>2</sub> | Sn (69, 70)

Sn<sub>2</sub>Pb | Pb and Sn salts | HgCl | Hg (60)

**Tl**

Tl<sub>2</sub>Bi | TlCl(satd. at 15°) | Tl (50)

Tl | TlCl(satd.) | N KCl | HgCl | Hg+

*E*<sub>25</sub> = 729.0 ± 0.1 mv; *dE/dt* = 0.75 mv/°C (39)

Tl<sub>55</sub>%Hg | TlCl(satd.) | N KCl | HgCl | Hg+

*E*<sub>25</sub> = 726.2 ± 0.3 mv; *dE/dt* = 0.71 mv/°C (39)

Tl<sub>2</sub>Hg | Tl<sub>2</sub>SO<sub>4</sub> | Tl<sub>2</sub>Hg

Accurate values 0, 15, 20, 30° for wide variation of *x* and *y* (79, 85, 86, 87); cf. (2)

Tl<sub>2</sub>Pb | TlCl(satd.) | Tl (4, 50)

Also with Sb and Sn

**Zn**

MZn<sub>2</sub> | ZnSO<sub>4</sub> | Zn

M	Lit.	M	Lit.	M	Lit.
Ag.....	(35, 45, 68)	Co.....	(27)	Ni.....	(101)
Ag + Pb...	(45)	Cd.....	(68)	Pb.....	(29, 46)
Au.....	(68)	Cu.....	(89)	Pb + Sn..	(47)
Bi.....	(29, 35, 49)	Fe.....	(102)	Sb.....	(35, 69)
Bi + Sb....	(49)	Hg.....	<i>v. infra</i>	Sn.....	(29, 35)

Zn<sub>2</sub>Cu | N Na<sub>2</sub>SO<sub>4</sub> + *y*N ZnSO<sub>4</sub> + (1 - *y*)N CuSO<sub>4</sub> | N KCl | HgCl | Hg (94)

Zn<sub>2</sub>Hg | ZnSO<sub>4</sub> | Zn<sub>2</sub>Hg

Accurate values at 0, 0.2, 12.1, 15, 25, 35, 50°; wide range of *x* and *y* (13, 19, 34, 59, 82, 83)

+Zn<sub>0.6</sub>%Hg | ZnSO<sub>4</sub> | Zn<sub>1.2</sub>%Hg  
ZnCl<sub>2</sub>

*E* (mv) = 6.964(1 + 0.00443*t*); range, *t* = 10 to 50° (9)

Zn<sub>10</sub>%Hg | ZnSO<sub>4</sub>·7H<sub>2</sub>O, Hg<sub>2</sub>SO<sub>4</sub> | Hg+

*E*<sub>25</sub> = 1419.99 ± 0.05 mv; 10<sup>3</sup> *dE/dP* = -12.2 ± 0.3, mv/atm. (17)

Zn<sub>7</sub>%Hg | ZnCl<sub>2</sub> (*p* %), MCl | M+ (99)

M	<i>p</i> , %	<i>E</i> <sub>25</sub> , mv	±	10 <sup>3</sup> <i>dE/dP</i> , mv/atm.
Ag.....	35.03	958.72	0.05	-1.22 ± 0.2
Ag.....	65.59	846.66	0.1	-2.66 ± 0.2
Hg.....	35.03	1005.61	0.05	+1.54 ± 0.15
Hg.....	65.59	892.8	0.2	+0.04 ± 0.03

Non-Aqueous Liquids

Ca<sub>0.0546</sub>%Hg | CaI<sub>2</sub> in pyridine | Ca<sub>0.11</sub>%Hg (5)  
CaCl<sub>2</sub> in alcohol

For similar cells in CH<sub>3</sub>OH at 80°C, *v.* (6)

Ca<sub>2</sub>Hg | CaI<sub>2</sub> | AgNO<sub>3</sub> | Ag

In pyridine (7)

Cd<sub>2</sub>Bi | CdCl<sub>2</sub> in LiCl + KCl + KOH | Cd

*E* ± 2 mv at 431, 479, 533 and 577°; same with Sn (97)

+K<sub>0.2216</sub>%Hg | KI in ethylamine | K

*E*<sub>25</sub> = 1048.1 ± 0.3 mv; *dE/dt* = ± 0.272 (56)

+Li<sub>0.0144</sub>%Hg | LiCl in pyridine | Li<sub>0.025</sub>%Hg

*E*<sub>7</sub> = 16.9 ± 0.2 mv; LiCl almost satd. (82, 83)

+Li<sub>0.035</sub>%Hg | LiI in pyridine | Li

*E*<sub>25</sub> = 950.2 ± 1 mv; *dE/dt* = 0.322; LiCl almost satd. (57)

Mg<sub>2</sub>Hg | 0.35M MgCl<sub>2</sub> | 0.35M MgCl<sub>2</sub> | HgCl | Hg

In methyl alcohol at -80°C (8)

Mg<sub>2</sub>Hg | MgI<sub>2</sub> | AgNO<sub>3</sub> | Ag in pyridine (8)

+Na<sub>0.206</sub>%Hg | NaI in ethylamine | Na

*E*<sub>25</sub> = 845.6 ± 0.1 mv; *dE/dt* = 0.0408 (58)

Na<sub>2</sub>Hg | 0.1N NaI in pyridine | Hg (41)

Na<sub>2</sub>Hg | NaOH in 95% alcohol | Hg<sub>2</sub>O | Hg (32)

Pb<sub>2</sub>Hg | PbBr<sub>2</sub>(solid) | Pb<sub>2</sub>Hg, 263 to 403°K (40)

Pb<sub>2</sub>Zn | *y* ZnCl<sub>2</sub> + (1 - *y*) PbCl<sub>2</sub> | PbCl<sub>2</sub> | Pb, 515° (75)

+Rb<sub>0.217</sub>%Hg | RbI in C<sub>2</sub>H<sub>5</sub>NH<sub>2</sub> + NH<sub>3</sub> | Rb

*E*<sub>25</sub> = 1074.5 ± 1 mv (55)



$\text{Sn}_2\text{Hg} \mid \text{SnCl}_2 \text{ in pyridine } \mid \text{Sn}_2\text{Hg}$   
 $E \pm 0.4 \text{ mv at } 25 \text{ and } 50^\circ; x, 0 - 100\% \text{ (36)}$   
 $\text{Zn}_2\text{Cd} \mid \text{ZnCl}_2 \text{ in LiCl} + \text{KCl} + \text{KOH} \mid \text{Zn}$   
 $E \pm 0.2 \text{ mv at } 436, 464, 541 \text{ and } 572^\circ \text{ (97)}$   
 $\text{Zn}_2\text{Cu} \mid \text{ZnCl}_2 \mid \text{Zn} \text{ (89)}$   
 $\text{Zn}_2\text{Sb} \mid \text{ZnCl}_2 \mid \text{Glass} \mid \text{Zn} \text{ (96)}$   
 $\text{Zn}_2\text{Sn} \mid \text{ZnCl}_2 \text{ in LiCl} + \text{KCl} + \text{KOH} \mid \text{Zn}$   
 $E \pm 0.2 \text{ mv at } 431, 466, 537, 570^\circ \text{ (97)}$

## LITERATURE

(For a key to the periodicals see end of volume)

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## THE EMF OF CONCENTRATION CELLS

H. S. HARNED

CONTENTS	MATIERES	INHALTSVERZEICHNIS	INDICE	PAGE
Abbreviations and symbols.	Abréviations et symboles.	Abkürzungen und Zeichen.	Abbreviazione e simboli . . .	322
True concentration cells.	Piles de concentration vraies.	Wahre Konzentrationsketten.	Pile di concentrazione propriamente dette.	
Aqueous solutions.	Solutions aqueuses.	Wässrige Lösungen.	Soluzioni acquose . . . . .	322
Non-aqueous solutions.	Solutions non aqueuses.	Nichtwässrige Lösungen.	Soluzioni non acquose . .	329
Cells with salt bridges.	Piles avec liaisons salines.	Ketten mit Salzen als Zwischenelektrolyt.	Pile con ponti salini.	
Aqueous solutions.	Solutions aqueuses.	Wässrige Lösungen.	Soluzioni acquose . . . . .	330
Non-aqueous solutions.	Solutions non aqueuses.	Nichtwässrige Lösungen.	Soluzioni non acquose . .	331

For the purpose of defining the scope of this section a concentration cell will be defined as one whose emf serves as a measure of the free energy change corresponding to a definite change in the activity of a molecular (or ionic) species in the solution.<sup>1</sup>

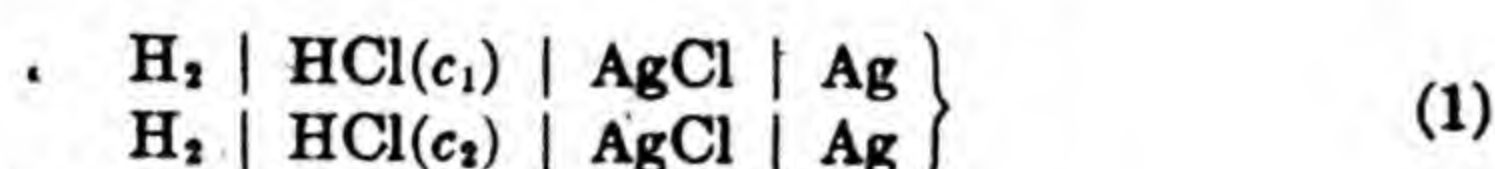
The section is divided into two parts as follows:

## Part I. True concentration cells

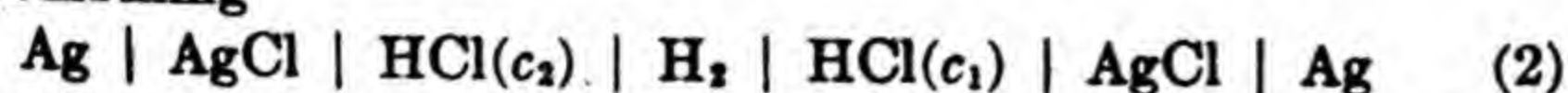
These include all cells whose total emf is a direct measure of the free energy change. These are of two types as follows:

## Type 1. Cells without transference

Example:



or by combining



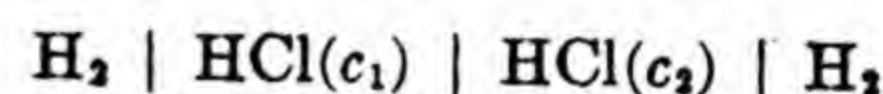
The cell reaction of cell (2) represents per faraday, the transfer of one equivalent of HCl from  $c_2$  (activity  $a_2$ ) to  $c_1$  (activity  $a_1$ ).

The equation for this cell is,  $E = (RT/F) \log a_2/a_1$ .

<sup>1</sup> For cells whose emf is a function of the activity of a molecular species in the electrode, v. p. 319.

## Type 2. Cells with transference

Example:



The equation for this type is,  $E = (nRT/F) \log a_1/a_2$ , where  $n$  is the number of equivalents transferred from activity  $a_1$  to  $a_2$  per faraday.

## Part II. Cells with salt bridges

Each cell listed in this group is composed of one of the standard reference electrodes joined (usually by a salt bridge) to a half cell containing the ion-species whose activity is sought. If from the total emf of such a cell, the emf of the reference electrode plus the emf's at the liquid junctions be subtracted, the result is a measure of the activity of the given ion species under the conditions which prevail in the other half of the cell.

Since the correction for liquid junction potentials is in most cases a matter of considerable uncertainty in the present state of our knowledge, these cells are listed by literature reference only.



## ABBREVIATIONS, SIGNS AND SYMBOLS

$E_t$	Emf in volts at $t$ , °C.
mv	Millivolts.
	Used to indicate a boundary between phases and to denote a liquid junction.
s, l, g	Solid, liquid, gas.
$N$	Gram-equivalents per liter.
$c$	Formula-weights per liter.
$m$	Formula-weights per kg of $H_2O$ .
$x$	Wt. %.
satd.	Saturated solution.

## LITERATURE

The older literature is not given except in cases where later and more accurate data are not available. For this older literature, see (1, 10).

## I. TRUE CONCENTRATION CELLS

The positive end of the cell is marked +; negative values of  $E$  indicate a reversal of this polarity

## AQUEOUS SOLUTIONS

A-B Table.—Standard arrangement (v. Vol. III, p. viii) in order of the molecular species whose concentration changes

$Cl_2$  (117); cf. (127, 177)

+Pt |  $Cl_2(p)$ , HCl(0.1N) | HgCl | Hg

$p$ (atm.)	$E_{25}$	$p$ (atm.)	$E_{25}$	$p$ (atm.)	$E_{25}$
0.0490	1.0508	0.0249	1.0424	0.00629	1.0242
0.0492	1.0509	0.0243	1.0419	0.00631	1.0243
0.0495	1.0510	0.0124	1.0330	0.00298	1.0154
0.0247	1.0421	0.0125	1.0330	0.00293	1.0150

## HCl

$H_2$  | HCl( $m$ ) | AgCl | Ag+

$10^3m$	$E_{25} \pm 0.0_2$	Lit.	$10^3m$	$E_{25} \pm 0.0_2$	$10^3m$	$E_{25} \pm 0.0_2$	Lit.
48.26	0.3874	(120)	4.83	0.5002	0.242	0.6514	(120)
9.65	.4658	(120)	1.00	0.5791	0.136	(0.6805)	(120)
10	.4665	(87)	0.483	0.6161			

(164)

$m$	$E_{25}$	$m$	$E_{25}$	$m$	$E_{25}$
0.01002	0.46376	0.09642	0.35393	0.5013	0.27195
0.01010	0.46331	0.09834	0.35316	0.6367	0.25902
0.01031	0.46228	0.2030	0.31774	0.9377	0.23696
0.04986	0.38582	0.3981	0.28407	1.0008	0.23290
0.05005	0.38568	0.5009	0.27197	1.5346	0.20534

(69)

$m$	$E_{20}$	$m$	$E_{20}$	$m$	$E_{20}$
0.01000	0.46303	0.10000	0.35315	0.5000	0.27419
0.02000	0.42968	0.20000	0.31998	0.7000	0.25611
0.05000	0.38602	0.3500	0.29244	1.0000	0.23564

(144)

$m$	$E_{25}$	$m$	$E_{25}$	$m$	$E_{25}$
0.0001182	0.6897	0.0006793	0.5987	0.004006	0.5094
0.0001529	0.6748	0.0008540	0.5870	0.007687	0.4768
0.0001602	0.6726	0.0008915	0.5849	0.01166	0.4565
0.0004185	0.6233	0.001376	0.5628	0.01970	0.4309
0.0004381	0.6210	0.001467	0.5597	0.02263	0.4242
0.0004579	0.6189	0.001705	0.5522	0.03616	0.4015
0.0005060	0.6137	0.001850	0.5480		
0.0005071	0.6137	0.003377	0.5178		

$$E_t = E_{25} [1 + \alpha(t - 25) + \beta(t - 25)^2] \quad (146)$$

$m$	$E_{15}$	$E_{25}$	$E_{35}$	$10^6\alpha$	$10^6\beta$
0.33314	0.29678	0.29348	0.28958	-1226.6	-10.22
0.09534	0.35600	0.35453	0.35270	-465.4	-5.08
0.03324	0.40530	0.40545	0.40513	-20.97	-5.80
0.00948	0.46452	0.46666	0.46824	398.6	-6.00
0.003378	0.51325	0.51696	0.52023	675.0	-4.26
0.000999	0.57308	0.57893	0.58421	960.7	-4.81

$H_2$  | HCl( $m$ ) | HgCl | Hg+

$$E_t = E_{25} [1 + \alpha(t - 25) + \beta(t - 25)^2] \quad (51)$$

$m$	$E_{15}$	$E_{25}$	$E_{35}$	$10^6\alpha$	$10^6\beta$
4.484	0.15759	0.15506	0.15125	-2384	-7.82
1.9278	0.23769	0.23589	0.23304	-1137	-7.06
1.0381	0.27919	0.27802	0.27595	-663	-8.23
0.7714	0.29654	0.29571	0.29411	-460	-8.20
0.5095	0.31912	0.31865	0.31765	-253	-6.00
0.3376	0.33845	0.33836	0.33794	-75	-4.96
0.1004	0.39764	0.39884	0.40013	386	-6.47
0.03332	0.45020	0.45258	0.45557	715	-5.47
0.01001	(0.5271)	(0.5302)	(0.5369)	(1010)	(26.1)
0.003333		(0.8040)	(0.8105)		

$m$ (119)	$E_{25}$	$m$ (119)	$E_{25}$
0.01006	0.5109	6.75	0.0972
0.1009	0.39895	10.0	0.03025
1.029	0.2779	16.0	0.06625
2.25	0.2231		

Hg | HgCl | HCl( $c$ ) |  $H_2$  | HCl( $c = 1$ ) | HgCl | Hg+ (31)

$c$	$E_{25}$	$c$	$E_{25}$	$c$	$E_{25}$
2	0.0490	6	0.1825	10	0.2940
3	0.0880	7	0.2138	11	0.3220
4	0.1190	8	0.2420	11.5	0.3360
5	0.1520	9	0.2630		

+ $Cl_2$ (1 atm.) | HCl( $c$ ) |  $H_2$

Values of  $E_{30}(\pm 0.006)$  from  $c = 5$  to 12 (43, 139); cf. (117)

Ag | AgCl | HCl( $c_1$ ) | HCl( $c_2$ ) | AgCl | Ag+ (92)

$c_1$	$c_2$	$E_{18}$	$c_1$	$c_2$	$E_{18}$
0.03330	0.003329	0.09159	0.01665	0.001665	0.09232
0.01665	0.003329	0.06426	0.01113	0.001665	0.07662
0.01113	0.003329	0.04815	0.008315	0.001665	0.06485
0.008308	0.003329	0.03658	0.006686	0.001665	0.05612
0.006661	0.003329	0.02777	0.005561	0.001665	0.04882
0.03342	0.001665	0.11951			

Hg | HgCl | HCl( $c_1$ ) | HCl( $c_2$ ) | HgCl | Hg+ (37, 48); cf. (41, 57, 141, 163)

$c_1$	$c_2$	$E_{18}$	$c_1$	$c_2$	$E_{18}$
0.1	0.05	0.02	0.01	0.1	0.1
0.05	0.02	0.01	0.002	0.002	0.002
0.0272	0.0361	0.0278	0.0665	0.1596	

+ $H_2$  | HCl( $c_1$ ) | HCl( $c_2$ ) |  $H_2$  (48)

$c_1$	$c_2$	$E_{18}$	$c_1$	$c_2$	$E_{18}$
0.1	0.1	0.1	0.05	0.02	0.02
0.05	0.02	0.01	0.02	0.01	0.01
0.00498	0.01138	0.01730	0.00685	0.00532	

$c_2 = 1$  (31)

$c_1$	$E_{25}$	$c_1$	$E_{25}$	$c_1$	$E_{25}$
2	0.0082	6	0.0321	10	0.0666
3	0.0144	7	0.0395	11	0.0775
4	0.0195	8	0.0484	11.5	0.0836
5	0.0255	9	0.0571		



**HCl.—(Continued)** $H_2 | HCl, MCl_a | HgCl | Hg +$ 

HCl	MCl <sub>a</sub>	t	Lit.
$c = 0.09$ to $0.01$ .....	KCl $\left\{ \begin{array}{l} c = 0.01 \text{ to } 0.09 \\ m = 0.0 \text{ to } 0.1 \\ c = 0.0 \text{ to } 3.0 \\ m = 0.0 \text{ to } 3.3 \end{array} \right.$	25	(122)
$m = 0.1$ to $0.01$ .....		25	(32)
$c = 0.1$ .....		25	(72)
$m = 0.1004$ .....		18	
$m = 0.1004$ .....	NaCl, $m = 0.1$ to $3.7$	25	(74)
$m = 0.1004$ .....	LiCl, $m = 0.4$ to $4.5$	30	
$m = 0.01$ to $0.1$ .....	LiCl, $m = 0.4$ to $4.0$	25	(86)
$m = 0.1$ .....	BaCl <sub>2</sub> , $m = 0.1$ to $1.3$	18	
$m = 0.1$ .....	SrCl <sub>2</sub> , $m = 0.1$ to $1.0$	25	(80)
$m = 0.1$ .....	CaCl <sub>2</sub> , $m = 0.1$ to $1.0$		
$m = 0.01$ .....	KCl, $m = 0.1$ to $1.0$	30	
$m = 0.005$ to $1.5$ .....	BaCl <sub>2</sub> , $m = 0.00625$ to $0.9$	25	(154)
$m = 0.125$ to $0.375$ .....	LaCl <sub>3</sub> , $m = 0.00417$ to $0.125$		
$m = 0.001$ to $3$ .....	$\left\{ \begin{array}{l} KCl, m = 0.0 \text{ to } 3 \\ NaCl, m = 0.0 \text{ to } 3 \\ LiCl, m = 0.0 \text{ to } 3 \end{array} \right.$	25	(79)

 $H_2 | HCl, MCl_a | AgCl | Ag +$ 

HCl	MCl <sub>a</sub>	t	Lit.
$m = 0.01$ to $0.1$ .....	$\left\{ \begin{array}{l} KCl, m = 0.01 \text{ to } 0.1 \\ NaCl, m = 0.01 \text{ to } 0.1 \\ LiCl, m = 0.01 \text{ to } 0.1 \\ CsCl, m = 0.01 \text{ to } 0.1 \end{array} \right.$	20	(69)

$Ag | AgCl | HCl(c_1), HNO_3(c_2) | HNO_3(c_2), HCl(0.002c) | AgCl | Ag +$

For  $c_1 = 0.01, 0.02$ , and  $0.04$  resp.,  $c_2 = 0.005, 0.01, 0.02$ , and  $0.04$ .  $18^\circ$  (157)

$+H_2 | HCl(0.1m), \text{gelatin}(x\%) | \text{gelatin}(x\%), HCl(0.1m) | H_2$   
also  $Hg | HgCl | HCl(0.1m), \text{gelatin}(x\%) | \text{gelatin}(x\%), HCl(0.01m) | HgCl | Hg +$   
 $x = 0.0$  to  $20.0, 25^\circ$  (57)

**HBr** $H_2 | HBr(m) | AgBr | Ag +$ 

m	E <sub>25</sub>	Lit.	m	E <sub>25</sub>	Lit.	m	E <sub>25</sub>	Lit.
0.01	0.3141	(118)	0.1086	0.1982	(121)	0.497	0.1214	(121)
0.03	0.2604	(118)	0.1878	0.1713	(121)	0.755	0.0980	(121)
0.085	0.2101	(121)	0.2400	0.1585	(121)	1.010	0.0804	(121)
0.1	0.2022	(118)	0.3075	0.1463	(121)	1.505	0.0535	(121)

 $H_2 | HBr, MBr_a | AgBr | Ag +$ 

HBr	MBr <sub>a</sub>	t	Lit.
$m = 0.01$ to $0.1$ .....	$\left\{ \begin{array}{l} KBr, m = 0.0 \text{ to } 3 \\ NaBr, m = 0.0 \text{ to } 3 \end{array} \right.$	25	(84)

 $+Pt | \frac{1}{2}Br_2(c_1), HBr(c_2) | H_2$  (15)

c <sub>1</sub>	c <sub>2</sub>	pH <sub>2</sub> (mm)	pBr <sub>2</sub> (mm)	pHBr (mm)	E <sub>30</sub>
0.049	11.5	742.5	0.682	12.0	0.573
0.125	10.2	753.6	1.509	2.25	0.625
0.127	8.7	760.6	1.448	1.119	0.636

 $H_2 | HBr(c_1) | HBr(c_2) | H_2 +$  (133)

$Hg | HgBr | HBr(0.126c) | HBr(0.0132c) | HgBr | Hg +$   
 $E_{18} = 0.0932$  (141)

**I<sub>2</sub>** $+ [Pt] | I_2(c_1), HI(c_2) | HI(c_2) | H_2$  (176)

c <sub>1</sub>	c <sub>2</sub>	E <sub>31.6</sub>	E <sub>34.2</sub>	E <sub>31.6</sub>
0.335	4.62	0.3028	0.2789	0.2466
0.29	5.8	0.2372	0.2126	0.1819
0.595	5.8	0.2448	0.2228	0.1918

 $[Pt] | I_2(c_1), KI(c_2) | KI(c_2), I_2(c_3) | [Pt] +$  (107)

c <sub>1</sub>	c <sub>2</sub>	c <sub>3</sub>	E <sub>20.4</sub>	c <sub>1</sub>	c <sub>2</sub>	c <sub>3</sub>	E <sub>20.4</sub>
0.05	0.115	0.005	0.0444	0.0322	1.0	0.0139	0.0108
0.005	0.115	0.0005	0.0304	0.056	1.0	0.0139	0.0184
0.05	0.23	0.005	0.0352	0.109	1.0	0.0139	0.0273
0.005	0.23	0.0005	0.0297	0.209	1.0	0.0139	0.0376
0.05	0.344	0.005	0.0326	0.279	1.0	0.0139	0.0434
0.005	0.344	0.0005	0.0295	0.362	1.0	0.0139	0.0491
				0.508	1.0	0.0139	0.0588

 $+I_2(s) | KI(c_1) | KI(c_1), I_2(0.035c) | [Pt]$  (108)

c <sub>1</sub>	E <sub>25</sub>	c <sub>1</sub>	E <sub>25</sub>
0.025	0.0640	0.5	0.1040
0.05	0.0728	0.7	0.1099
0.115	0.0830	0.85	0.1136
0.344	0.0987	1.0	0.1172

 $+I_2(s) | KI(c_1) | NH_4NO_3(10c) | KI(c_1), I_2(0.035c) | [Pt]$  (108)

c <sub>1</sub>	E <sub>25</sub>	c <sub>1</sub>	E <sub>25</sub>
0.025	0.0670	0.5	0.1086
0.05	0.0762	0.7	0.1154
0.115	0.0869	0.85	0.1200
0.344	0.1031	1.0	0.1252

**HI** $H_2 | HI(m) | AgI | Ag +$  (150)

m	E <sub>25</sub>	E <sub>30</sub>	E <sub>35</sub>
0.00505	0.12417	0.12707	0.12964
0.01045	0.08825	0.09060	0.09262
0.01981	0.05735	0.05931	0.06083
0.05040	0.00106	0.01128	0.01235
0.07914	-0.01210	-0.01128	-0.01073
0.1297	-0.03615	-0.03556	-0.03531
0.2461	-0.06905	-0.06864	-0.06829

**H<sub>2</sub>SO<sub>4</sub>** $H_2 | H_2SO_4(m) | Hg_2SO_4 | Hg +$  (155)

m	E <sub>25</sub> ± 0.032	m	E <sub>25</sub> ± 0.032
0.005	0.8160	2.313	0.6442
0.05	0.7546	2.922	0.6315
0.1112	0.7343	3.859	0.6145
0.2789	0.7114	4.827	0.5975
0.5607	0.6929	6.168	0.5770
0.8453	0.6812	8.295	0.5495
1.133	0.6720	13.88	0.4985
1.717	0.6571		

 $H_2 | H_2SO_4(c) | Hg_2SO_4 | Hg +$  (28)

c = 0.00482		c = 0.01506		c = 0.0673	
t	E	t	E	t	E
15.7	0.8240	15.7	0.7925	13.7	0.7494
25.7	0.8243	25.7	0.7927	25.2	0.7493
37.8	0.8246	37.8	0.7930	35.7	0.7491
49.5	0.8249	49.5	0.7933	47.8	0.7485
64.1	0.8259	64.1	0.7939	59.9	0.7486
79.9	0.8263	79.9	0.7949	82.1	0.7527

c = 0.2784		c = 1.235		c = 4.837	
t	E	t	E	t	E
13.7	0.7155	13.9	0.6402	15.6	0.6012
25.2	0.7144	25.7	0.6371	26.1	0.5986
35.7	0.7132	37.4	0.6333	37.0	0.5957
47.8	0.7116	49.4	0.6295	48.7	0.5925



$\text{H}_2\text{SO}_4$ —(Continued)

$c = 0.2784$		$c = 1.235$		$c = 4.837$	
$t$	$E$	$t$	$E$	$t$	$E$
59.9	0.7104	60.5	0.6267	60.8	0.5892
82.1	0.7132	70.9	0.6240	73.8	0.5857
		80.2	0.6207		

$c = 0.1110$		$c = 14.87$	
$t$	$E$	$t$	$E$
15.6	0.5698	16.6	0.4995
26.1	0.5673	28.4	0.4970
37.0	0.5646	40.8	0.4943
48.7	0.5617	55.6	0.4906
60.8	0.5582	70.2	0.4864
73.8	0.5542		

 $+\text{H}_2 \mid \text{H}_2\text{SO}_4(c) \mid \text{PbSO}_4 \mid \text{Pb}$  (44)

$c$	0.513	1.01	2.30	3.20	7.70
$E_0$	0.269	0.282	0.317	0.339	0.426

 $\text{H}_2 \mid \text{H}_2\text{SO}_4(c) \mid \text{PbSO}_4 \mid \text{PbO}_2 +$  (44)

$c$	0.513	1.01	2.30	3.20	7.70
$E_0$	1.610	1.617	1.654	1.682	1.801

 $+\text{PbO}_2 \mid \text{PbSO}_4 \mid \text{H}_2\text{SO}_4(c) \mid \text{PbSO}_4 \mid \text{Pb}$ 

$c$	1.000	0.360	0.180	0.111	0.0505	0.0124	0.00046
$E_0$	1.896	1.841	1.808	1.782	1.745	1.672	1.472

 (44)

$c$	$E_{25}$	$c$	$E_{25}$	$c$	$E_{25}$
0.077	1.744	1.16	1.929	3.89	2.067
0.200	1.815	1.66	1.958	4.67	2.094
0.658	1.892	2.60	2.004	6.97	2.198
0.891	1.911	2.99	2.029		

 (97)
 $+\text{Pb} \mid \text{PbSO}_4 \mid \text{H}_2\text{SO}_4(c_1) \mid \text{H}_2\text{SO}_4(c_2) \mid \text{PbSO}_4 \mid \text{Pb}$   
 $c_2 = 2.99$  (97)

$c_1$	$E_{25}$	$c_1$	$E_{25}$
0.077	0.1033	2.39	0.0115
0.200	0.0762	2.63	0.0038
0.658	0.0507	4.14	-0.0157
1.66	0.0248	4.67	-0.0179

$c_1$	$c_2$	$E_{17}$	$c_1$	$c_2$	$E_{17}$
3.0	1.5	0.0315	0.188	0.094	0.016
1.5	0.75	0.021	0.375	0.094	0.0308
0.75	0.375	0.017	0.75	0.094	0.0462
0.375	0.188	0.015			

 (140)
 $+\text{H}_2 \mid \text{H}_2\text{SO}_4(0.1m) \mid \text{H}_2\text{SO}_4(0.01m) \mid \text{H}_2$   
 $E_{25} = 0.01131$  (53) $\text{H}_2 \mid \text{H}_2\text{SO}_4(c) \mid \text{H}_2\text{SO}_4(c = 3) \mid \text{H}_2 +$  (97)

$c$	$E_{17}$	$c$	$E_{17}$
0.046	-0.0252	7.19	0.0281
0.184	-0.0179	10.0	0.0557
0.364	-0.0149	11.07	0.0686
1.49	-0.0058	12.37	0.0928
4.50	0.0082	13.17	0.1192

 $\text{Hg} \mid \text{Hg}_2\text{SO}_4 \mid \text{H}_2\text{SO}_4(0.1m) \mid \text{H}_2\text{SO}_4(0.01m) \mid \text{Hg}_2\text{SO}_4 \mid \text{Hg} +$   
 $E_{25} = 0.04925$  (54) $\text{H}_2 \mid \text{H}_2\text{SO}_4, \text{M}_2\text{SO}_4 \mid \text{Hg}_2\text{SO}_4 \mid \text{Hg} +$ 

$\text{H}_2\text{SO}_4$	$\text{M}_2\text{SO}_4$	$t$	Lit.
$m = 0.1$ and $0.01$ .....	$\left\{ \begin{array}{l} \text{K}_2\text{SO}_4, m = 0.0 \text{ to } 0.5 \\ \text{Na}_2\text{SO}_4, m = 0.0 \text{ to } 1 \\ \text{MgSO}_4, m = 0.0 \text{ to } 1 \end{array} \right\}$	25	(85)
$m = 0.05$ and $0.005$ .....	$\left\{ \begin{array}{l} \text{K}_2\text{SO}_4, c = 0.0 \text{ to } 0.625 \\ \text{Na}_2\text{SO}_4, c = 0.0 \text{ to } 2 \\ \text{Li}_2\text{SO}_4, c = 0.0 \text{ to } 2 \end{array} \right\}$	25	(7)
$m = 0.05$ to $2$ .....	$\text{Na}_2\text{SO}_4, m = 0.05 \text{ to } 2$	25	(156)

 $\text{NH}_3$  $v. \text{CuOH}, \text{Zn(OH)}_2, \text{AgNO}_3, \text{Cd(OH)}_2$  and  $\text{AgCl}$  $\text{NH}_4\text{Cl}$  $\text{Hg} \mid \text{HgCl} \mid \text{NH}_4\text{Cl}(0.1N) \mid \text{NH}_4\text{Cl}(0.01N) \mid \text{HgCl} \mid \text{Hg} +$   
 $E_{18} = 0.0546$  (141) $(\text{C}_6\text{H}_5\text{CH}_2)_3(\text{CH}_3)\text{NCl}$ , Tribenzylmethylammonium bromide (T) $\text{Ag} \mid \text{AgBr} \mid \text{TBr}(c_1) \mid \text{TBr}(c_2) \mid \text{TBr}(c_3) \mid \text{AgBr} \mid \text{Ag} +$   
Also the same cell with salt bridges (45) $\text{PbCl}_2$  $\text{Pb}_2\text{Hg} \mid \text{PbCl}_2(c) \mid \text{AgCl} \mid \text{Ag} +$  (27)

$t, ^\circ\text{C}$	$c$	satd.	0.0265	0.00984
0		0.4864	0.4831	0.5092
16.7		0.4801	0.4859	0.5128
30.5		0.4747	0.4875	0.5153
40.5		0.4707	0.4884	0.5168
49.3		0.4672	0.4888	0.5177
58.3		0.4637	0.4888	0.5183
67.0		0.4601	0.4886	0.5186
76.0		0.4560	0.4882	0.5187
84.0		0.4529	0.4878	0.5184
92.2		0.4497	0.4868	0.5177

 $\text{Pb(NO}_3)_2$  $+\text{Pb}_2\text{Hg} \mid \text{Pb(NO}_3)_2(c_1) \mid \text{Pb(NO}_3)_2(c_2) \mid \text{Pb}_2\text{Hg}$ 

$c_1$	0.5	0.05	0.005	0.5
$c_2$	0.05	0.005	0.0005	0.0005
$E_{\text{room}}$	0.026	0.035	0.043	0.104

 (27)
 $+\text{Pb} \mid \text{Pb(NO}_3)_2(c_1) \mid \text{Pb(NO}_3)_2(c_2) \mid \text{Pb}$ 

$c_1$	$c_2$	$E_{\text{room}}$	Lit.
0.5	0.05	0.030	(105)
0.05	0.005	0.040	

 $\text{Pb(C}_2\text{H}_3\text{O}_2)_2$  $+\text{Pb} \mid \text{PbAc}_2(c_1) \mid \text{PbAc}_2(c_2) \mid \text{Pb}$ 

$c_1$	$c_2$	$E_{\text{room}}$	Lit.
0.5	0.05	0.010	(105)
0.05	0.005	0.015	

 $\text{Zn(OH)}_2$  $\text{Zn} \mid \text{ZnO}(c_1), \text{NaOH}(c_2) \mid \text{ZnO}(c_1) \mid \text{NaOH}(c_3) \mid \text{Zn} +$   
 $c_1 = 0.012 \text{ to } 0.0024; c_2 = 0.37 \text{ to } 1.95; c_3 = 0.09 \text{ to } 0.97;$   
room temp. (104) $\text{Zn} \mid \text{Zn(OH)}_2(c_1), \text{NH}_3(c_2) \mid \text{Zn(OH)}_2(c_1), \text{NH}_3(c_3) \mid \text{Zn}$   
 $c_1 = 0.125 \text{ to } 0.00825; c_2 = 3, 4, 5 \text{ and } 6; c_3 = 1.5, 2 \text{ and } 4;$   
25° (22)



ZnCl <sub>2</sub>					
Zn   ZnCl <sub>2</sub> (m and c)   AgCl   Ag +					
m	E <sub>25</sub>	m	E <sub>25</sub>	c	E <sub>25</sub>
(87)		(87)		(91)	
0.01021	1.1558	0.001253	1.2289	0.566	1.0306
0.006022	1.1742	0.000772	1.2475	1.112	1.0171
0.003112	1.1953	0.000649	1.2497	2.22	0.9740
0.001453	1.2219	0.0003995	1.2699		
		0.0003478	1.2701		

Zn <sub>1%</sub> Hg   ZnCl <sub>2</sub> (c)   HgCl   Hg + (110)			
c	E <sub>20.2</sub>	c	E <sub>20.2</sub>
9.97	0.8539	0.550	1.0626
6.76	0.9245	0.454	1.0683
6.16	0.9385	0.385	1.0755
4.54	0.9740	0.275	1.0851
3.08	1.0005	0.137	1.1081
1.54	1.0300	0.077	1.1269
1.10	1.0406	0.068	1.1309
0.77	1.0528	0.0616	1.1298
0.616	1.0573	0.034	1.1524

Zn<sub>2</sub>Hg | ZnCl<sub>2</sub>(c<sub>1</sub>) | HgCl | Hg | HgCl | ZnCl<sub>2</sub>(c<sub>2</sub>) | Zn<sub>2</sub>Hg  
 Also same with AgCl | Ag | AgCl bridge (66)  
 Zn | ZnCl<sub>2</sub>(m) | Cl<sub>2</sub>(p) | Pt (56)  
 t = 60.5 and 80.4°C; m = 0.07 to 25; p = 1 atm.  
 +Zn | ZnCl<sub>2</sub>(2.35c) | ZnCl<sub>2</sub>(0.144c) | Zn  
 E<sub>25</sub> = 0.0751 (30)  
 Zn | ZnCl<sub>2</sub>(m<sub>1</sub>) | ZnCl<sub>2</sub>(m<sub>2</sub>) | Zn (56)  
 t = 60.5 and 80.4°C; m<sub>1</sub> = 2.4 to 25; m<sub>2</sub> = 0.87 to 4.85  
 Pt | Cl<sub>2</sub>(p) | ZnCl<sub>2</sub>(m<sub>1</sub>) | ZnCl<sub>2</sub>(m<sub>2</sub>) | Cl<sub>2</sub>(p) | Pt (56)  
 t = 60.5 and 80.4°C; m<sub>1</sub> = 2.4 to 25; m<sub>2</sub> = 0.87 to 4.85; p = 1 atm.

ZnBr<sub>2</sub>  
 Zn<sub>2</sub>Hg | ZnBr<sub>2</sub>(c<sub>1</sub>) | HgBr | Hg | HgBr | ZnBr<sub>2</sub>(c<sub>2</sub>) | Zn<sub>2</sub>Hg  
 Also same cell with AgBr | Ag | AgBr bridge (67)

ZnSO <sub>4</sub>					
Zn-Hg(2-phase)   ZnSO <sub>4</sub> (m)   PbSO <sub>4</sub>   Pb-Hg(2-phase) +					
(24)					
m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.000658	0.6074	0.00506	0.5658	0.2532	0.5077
0.000670	0.6072	0.00910	0.5552	0.3518	0.5037
0.000687	0.6067	0.01712	0.5449	0.8584	0.4932
0.000702	0.6060	0.01824	0.5439	1.426	0.4858
0.001505	0.5898	0.04120	0.5317	2.052	0.4783
0.001648	0.5878	0.08532	0.5211	2.749	0.4685
0.003322	0.5737	0.1732	0.5122	3.419	0.4581

Zn <sub>1%</sub> Hg   ZnSO <sub>4</sub> (c)   Hg <sub>2</sub> SO <sub>4</sub>   Hg +					
c	E <sub>20.2</sub>	c	E <sub>20.2</sub>	c	E <sub>20.2</sub>
2.6	1.4306	1.5	1.4452	0.87	1.4545
		1.4520			

Zn <sub>2</sub> Hg   ZnSO <sub>4</sub> (c <sub>1</sub> )   PbSO <sub>4</sub>   Pb <sub>2</sub> Hg   PbSO <sub>4</sub>   ZnSO <sub>4</sub> (c <sub>2</sub> )   Zn <sub>2</sub> Hg +					
c <sub>1</sub>	E <sub>25</sub>	c <sub>2</sub>	E <sub>25</sub>	c <sub>2</sub>	E <sub>25</sub>
0.1	0.05	0.01			
0.01	0.005	0.001			
0.0427	0.0441	0.0522			

+Zn   ZnSO <sub>4</sub> (c <sub>1</sub> )   ZnSO <sub>4</sub> (c <sub>2</sub> )   Zn					
c <sub>1</sub>	E <sub>25</sub>	c <sub>2</sub>	E <sub>25</sub>	c <sub>2</sub>	E <sub>25</sub>
1.10	0.554	1.10	0.139	0.139	
0.554	0.277	0.139	0.0171	0.0101	
0.0062	0.0116	0.0171			

+Zn <sub>2</sub> Hg   ZnSO <sub>4</sub> ·7H <sub>2</sub> O   ZnSO <sub>4</sub> (satd.)   ZnSO <sub>4</sub> (c)   Zn <sub>2</sub> Hg			
t	c	E	Lit.
15	1.198	0.02045	(33)
25	1.371	0.02444	

Hg   Hg <sub>2</sub> SO <sub>4</sub>   ZnSO <sub>4</sub> ·7H <sub>2</sub> O   ZnSO <sub>4</sub> (satd.)   ZnSO <sub>4</sub> (c)   Hg <sub>2</sub> SO <sub>4</sub>   Hg +			
t	c	E	Lit.
15	1.198	0.0057	(33)
25	1.371	0.00648	

ZnC<sub>2</sub>O<sub>4</sub>  
 Zn | ZnC<sub>2</sub>O<sub>4</sub>(c<sub>1</sub>), K<sub>2</sub>C<sub>2</sub>O<sub>4</sub>(c<sub>2</sub>) | K<sub>2</sub>C<sub>2</sub>O<sub>4</sub>(c<sub>3</sub>), ZnC<sub>2</sub>O<sub>4</sub>(c<sub>4</sub>) | Zn  
 c<sub>1</sub> = 0.004 to 0.014; c<sub>2</sub> = 0.125, 0.25 and 0.5; c<sub>3</sub> = 0.0625 to 0.25; c<sub>4</sub> = 0.0019 to 0.0144; room temp. (104)

Cd(OH)<sub>2</sub>  
 Cd | Cd(OH)<sub>2</sub>(c<sub>1</sub>), NH<sub>3</sub>(c<sub>2</sub>) | NH<sub>3</sub>(c<sub>3</sub>), Cd(OH)<sub>2</sub>(c<sub>1</sub>) | Cd  
 c<sub>1</sub> = 0.0042 and 0.00835; c<sub>2</sub> = 5 and 6.45; c<sub>3</sub> = 2, 3.2, 3 and 4; 25° (22)

CdCl <sub>2</sub>			
Cd <sub>4.6%</sub> Hg   CdCl <sub>2</sub> (m)   AgCl   Ag +			
m	E <sub>25</sub> ± 1 mv	m	E <sub>25</sub> ± 1 mv
6.62	0.62203	0.0003363	0.8644
0.0995	0.6996	0.0002144	0.8803
0.0074	0.76305	0.0001527	0.8926
0.003519	0.7864	0.0001269	0.8978
0.002581	0.7958	0.0001137	0.9011
0.000924	0.8296	0.0001087	0.9023
0.000479	0.852	0.0001029	0.9060
0.0003659	0.8614		(87)

Cd   CdCl <sub>2</sub> (c)   AgCl   Ag + (13)			
c	E <sub>20</sub>	c	E <sub>20</sub>
0.493	0.7239	2.229	0.6995
0.525	0.7225	3.247	0.6915
0.651	0.7191	4.404	0.6834
1.006	0.7123	5.775	0.6743

Cd   CdCl <sub>2</sub> (m)   HgCl   Hg + (63)					
m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.00086	0.9155	0.0311	0.8198	5.035	0.7311
0.0031	0.8667	0.0622	0.8063	5.454	0.7302
0.0062	0.8727	0.0819	0.8014	5.909	0.7286
0.0086	0.8485	0.1556	0.7866	6.591	0.7182
0.0164	0.8325	0.3113	0.7752		

+Cd   CdCl <sub>2</sub> (c <sub>1</sub> )   CdCl <sub>2</sub> (c <sub>2</sub> )   Cd (12)					
c <sub>1</sub>	c <sub>2</sub>	E <sub>20</sub>	c <sub>1</sub>	c <sub>2</sub>	E <sub>20</sub>
1.097	0.4932	0.0083	3.394	0.3399	0.0287
1.580	0.5403	0.0113	2.464	0.2486	0.0259
2.062	0.4923	0.0160	2.052	0.2100	0.0244
2.552	0.5058	0.0191	1.596	0.1623	0.0244
3.444	0.4963	0.0252	1.062	0.1089	0.0244
4.144	0.4942	0.0309	0.4818	0.04822	0.0264
4.798	0.4871	0.0353	0.2080	0.02214	0.0275
4.096	0.4145	0.0318	0.0492	0.00563	0.0317

Ag   AgCl   CdCl <sub>2</sub> (c)   CdCl <sub>2</sub> (0.5c)   AgCl   Ag +			
c	E <sub>20</sub>	c	E <sub>20</sub>
0.697	0.00202	3.251	0.00822
0.880	0.00327	4.667	0.00782
1.136	0.00462	5.59	0.00642
1.653	0.00623	5.83	0.00588
2.426	0.00782		(13)



**CdBr<sub>2</sub>**  
Cd | CdBr<sub>2</sub>(m) | HgBr | Hg + (63)

m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.0012	0.7624	0.0476	0.6915	0.4756	0.6452
0.0029	0.7507	0.0732	0.6805	3.159	0.6051
0.0048	0.7368	0.1172	0.6733	4.192	0.6000
0.0117	0.7202	0.1877	0.6640		
0.0293	0.6993	0.2929	0.6551		

**CdSO<sub>4</sub>**  
Cd | CdSO<sub>4</sub>(m) | Hg<sub>2</sub>SO<sub>4</sub> | Hg + (63)

m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.0014	1.1438	0.1328	1.1178	1.386	1.0926
0.0055	1.1484	0.1386	1.1152	2.125	1.0809
0.0139	1.1399	0.2217	1.1130	2.656	1.0768
0.0554	1.1285	0.5542	1.1033	3.698	1.0656

+Cd | CdSO<sub>4</sub>(0.5c) | Hg<sub>2</sub>SO<sub>4</sub> | Hg | Hg<sub>2</sub>SO<sub>4</sub> | CdSO<sub>4</sub>(0.05c) | Cd  
E<sub>25</sub> = 0.020 (105)

+Cd | CdSO<sub>4</sub>(c<sub>1</sub>) | CdSO<sub>4</sub>(c<sub>2</sub>) | Cd

c <sub>1</sub> .....	1.09	1.09	0.541	(30)
c <sub>2</sub> .....	0.277	0.139	0.139	
E <sub>25</sub> .....	0.0108	0.0164	0.0099	

**Hg<sub>2</sub>(NO<sub>3</sub>)<sub>2</sub>**  
Hg | Hg<sub>2</sub>(NO<sub>3</sub>)<sub>2</sub>(c<sub>1</sub>), HNO<sub>3</sub>(0.1N) | HNO<sub>3</sub>(0.1N), Hg<sub>2</sub>(NO<sub>3</sub>)<sub>2</sub>(c<sub>2</sub>) | Hg +

c <sub>1</sub> .....	0.1	0.05	0.005	0.0005	(147)
c <sub>2</sub> .....	0.01	0.005	0.0005	0.00005	
E <sub>18</sub> .....	0.0266	0.0274	0.0290	0.0304	

**CuOH**  
Cu | CuOH(c<sub>1</sub>), NH<sub>3</sub>(c<sub>2</sub>) | NH<sub>3</sub>(c<sub>3</sub>), CuOH(c<sub>4</sub>) | Cu  
c<sub>1</sub> = 0.0001 to 0.002; c<sub>2</sub> = 0.37 to 1.76; c<sub>3</sub> = 0.5 and 0.37; c<sub>4</sub> = 0.0002 to 0.001; room temp. (16)

**CuCl**  
Cu | CuCl(c<sub>1</sub>), KCl(c<sub>2</sub>) | KCl(c<sub>3</sub>), CuCl(c<sub>4</sub>) | Cu  
c<sub>1</sub> = 0.047 to 0.05; c<sub>2</sub> = 0.1 to 2.0; c<sub>3</sub> = 0.05 to 1.0; c<sub>4</sub> = 0.047 to 0.05; room temp. (20, 21)

CuBr, analogue of CuCl above (21)

**CuSO<sub>4</sub>**  
Hg | Hg<sub>2</sub>SO<sub>4</sub> | CuSO<sub>4</sub>(m<sub>1</sub>) | Cu<sub>2</sub>Hg | CuSO<sub>4</sub>(m<sub>2</sub>) | Hg<sub>2</sub>SO<sub>4</sub> | Hg +

m <sub>1</sub> .....	0.1	0.5	0.5	(143)
m <sub>2</sub> .....	0.05	0.2	0.1	
E <sub>25</sub> .....	0.0089	0.0105	0.0190	

Cu | CuSO<sub>4</sub>(m) | Hg<sub>2</sub>SO<sub>4</sub> | Hg +  
E (±0.00023) = 0.3928 for m = 0.05; = 0.4226 for m = 0.005 (115); cf. (132)

+Cu | CuSO<sub>4</sub>(c<sub>1</sub>) | CuSO<sub>4</sub>(c<sub>2</sub>) | Cu

c <sub>1</sub> .....	0.01	0.921	0.5	0.05
c <sub>2</sub> .....	0.001	0.277	0.05	0.005
E <sub>25</sub> .....	0.0299	0.0098	0.022 (room)	
Lit.....	(61)	(30)	(105)	(105)

**Cu(NO<sub>3</sub>)<sub>2</sub>**  
Cu | Cu(NO<sub>3</sub>)<sub>2</sub>(c<sub>1</sub>) | Cu(NO<sub>3</sub>)<sub>2</sub>(10c<sub>1</sub>) | Cu +  
E = 0.048 for c<sub>1</sub> = 0.05; = 0.040 for c<sub>1</sub> = 0.005; room temp. (105)

**AgCl**  
Ag | AgCl(c<sub>1</sub>), NH<sub>3</sub>(c<sub>2</sub>) | NH<sub>3</sub>(c<sub>3</sub>), AgCl(c<sub>4</sub>) | Ag  
c<sub>1</sub> = 0.04 to 0.05; c<sub>2</sub> = 0.1 to 7.5; c<sub>3</sub> = 0.1 to 5.0; c<sub>4</sub> = 0.04 to 0.05; 17-18° (19)

**AgI**  
Ag | AgI(c<sub>1</sub>), KI(c<sub>2</sub>) | KI(c<sub>3</sub>), AgI(c<sub>4</sub>) | Ag  
c<sub>1</sub> = 0.032 to 0.01; c<sub>2</sub> = 0.33 to 2.0; c<sub>3</sub> = 0.17 to 2.0; c<sub>4</sub> = 0.0316 to 0.005; room temp. (18)

**AgNO<sub>3</sub>**  
+Ag | AgNO<sub>3</sub>(satd.) | AgNO<sub>3</sub>(0.0244c) | Ag  
E = 0.011 (3)

**AgNO<sub>3</sub>**  
+Ag | AgNO<sub>3</sub>(c<sub>1</sub>) | AgNO<sub>3</sub>(c<sub>2</sub>) | Ag

c <sub>1</sub>	c <sub>2</sub>	E <sub>25</sub>	c <sub>1</sub>	c <sub>2</sub>	E <sub>25</sub>
(11)			(40, 41)		
1.0	0.1	0.0472	0.5	0.1	0.0312
1.0	0.01	0.1036	0.1	0.01	0.0590
0.3	0.03	0.0536	0.01	0.001	0.0618
0.3	0.003	0.1138			
0.1	0.01	0.0566			
0.03	0.003	0.0601			
0.01	0.001	0.0602			

+Ag | AgNO<sub>3</sub>(c<sub>1</sub>) | NH<sub>4</sub>NO<sub>3</sub>(10c) | AgNO<sub>3</sub>(c<sub>2</sub>) | Ag

c <sub>1</sub> →c <sub>2</sub> .....	0.5→0.1	0.1→0.01	0.01→0.001	(40, 41)
E <sub>25</sub> .....	0.0286	0.0556	0.0579	

+Ag | AgNO<sub>3</sub>(c<sub>1</sub>) | KNO<sub>3</sub>(satd.) | AgNO<sub>3</sub>(c<sub>2</sub>) | Ag

c <sub>1</sub> →c <sub>2</sub> .....	0.5→0.1	0.1→0.01	(40, 41)
E <sub>25</sub> .....	0.0290	0.0555	

Ag | AgNO<sub>3</sub>(c<sub>1</sub>), NH<sub>3</sub>(c<sub>2</sub>) | NH<sub>3</sub>(c<sub>3</sub>), AgNO<sub>3</sub>(c<sub>4</sub>) | Ag  
c<sub>1</sub> = 0.04 to 0.05; c<sub>2</sub> = 0.1 to 7.5; c<sub>3</sub> = 0.1 to 2.5; c<sub>4</sub> = 0.04 to 0.05; room temp. (19)

+Ag | AgNO<sub>3</sub>(c<sub>1</sub>), KNO<sub>3</sub>(2c) | KNO<sub>3</sub>(2c), AgNO<sub>3</sub>(c<sub>2</sub>) | Ag

c <sub>1</sub> .....	0.20	0.10	0.05	0.025	(29)
c <sub>2</sub> .....	0.10	0.05	0.025	0.0125	
E <sub>10</sub> .....	0.01781	0.01762	0.01783	0.01749	

**AgCN; v. KAg(CN)<sub>2</sub>**  
**AgCNS**  
Ag | AgCNS(c<sub>1</sub>), KCNS(c<sub>2</sub>) | KCNS(c<sub>3</sub>), AgCNS(c<sub>4</sub>) | Ag  
c<sub>1</sub> = 0.032 to 0.1; c<sub>2</sub> and c<sub>3</sub> = 0.1 to 2.0; c<sub>4</sub> = 0.025 to 0.025; room temp. (17, 18)

**MgCl<sub>2</sub>**  
Hg | HgCl | MgCl<sub>2</sub>(c<sub>1</sub>) | MgCl<sub>2</sub>(c<sub>2</sub>) | HgCl | Hg + (59)

c <sub>1</sub>	c <sub>2</sub>	E <sub>18</sub>	c <sub>1</sub>	c <sub>2</sub>	E <sub>18</sub>
2.0	1.75	0.0019	0.5	0.1	0.0199
1.75	1.5	0.0025	0.1	0.01	0.0290
1.5	1.0	0.0057	0.01	0.001	0.0346
1.0	0.5	0.0104	0.001	0.0001	0.0358

Ag | AgCl | MgCl<sub>2</sub>(c<sub>1</sub>), MgSO<sub>4</sub>(2N) | MgSO<sub>4</sub>(2N), MgCl<sub>2</sub>(c<sub>2</sub>) | Ag +

10 <sup>3</sup> c <sub>1</sub> .....	200.05	20.05	2.049	(29)
10 <sup>3</sup> c <sub>2</sub> .....	20.05	2.049	0.250	
E <sub>10</sub> .....	0.0562	0.0573	0.0524	

**CaCl<sub>2</sub>**  
Ag | AgCl | CaCl<sub>2</sub>(m) | Ca<sub>2</sub>Hg | CaCl<sub>2</sub>(0.01m) | AgCl | Ag + (124)

m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.0350	0.0411	0.4655	0.1335	1.606	0.2105
0.0629	0.0606	0.6622	0.1543	1.960	0.2313
0.1032	0.0772	0.9608	0.1750	3.167	0.2856
0.2066	0.1014	1.003	0.1773	3.502	0.3005
0.3713	0.1235				



CaCl<sub>2</sub>—(Continued)

Ag   AgCl   CaCl <sub>2</sub> (m)   CaCl <sub>2</sub> (0.01m)   AgCl   Ag + (124)					
m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.0155	0.0060	0.0805	0.0284	1.013	0.0626
0.0201	0.0097	0.1612	0.0368	1.600	0.0716
0.0395	0.0190	0.3208	0.0460	2.586	0.0836
0.0497	0.0220	0.6162	0.0549		

SrCl<sub>2</sub>

Ag   AgCl   SrCl <sub>2</sub> (m)   SrCl <sub>2</sub> (0.01m)   AgCl   Ag + (124)					
m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.0291	0.0352	0.3458	0.1170	2.115	0.2030
0.0900	0.0722	1.049	0.1612	3.015	0.2356
0.1167	0.0798	1.403	0.1767		

Ag   AgCl   SrCl <sub>2</sub> (m)   SrCl <sub>2</sub> (0.01m)   AgCl   Ag + (124)					
m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.0158	0.0064	0.1466	0.0356	2.027	0.0721
0.0320	0.0157	0.3168	0.0453	2.954	0.0818
0.0456	0.0208	0.6246	0.0540		
0.0792	0.0277	1.269	0.0642		

BaCl<sub>2</sub>

Ag   AgCl   BaCl <sub>2</sub> (m)   Ba <sub>2</sub> Hg   BaCl <sub>2</sub> (m <sub>0</sub> )   AgCl   Ag + (124)					
m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.0302	0.0355	0.2978	0.1092	1.521	0.1718
0.1004	0.0742	0.9710	0.1532	1.650	0.1771

## (151)

m <sub>0</sub>	m	E <sub>25</sub>	m <sub>0</sub>	m	E <sub>25</sub>
0.003	0.03	0.0756	0.01	0.1	0.0744
0.005	0.05	0.0753	0.03	0.3	0.0739
0.003	0.1	0.1142	0.1	1	0.0766
0.005	0.1	0.0965	0.3	1.256	0.0686

Ag   AgCl, BaCl <sub>2</sub> (m)   BaCl <sub>2</sub> (m <sub>0</sub> )   AgCl   Ag + (124)					
m	E <sub>25</sub>	m	E <sub>25</sub>	m	E <sub>25</sub>
0.0192	0.00927	0.2426	0.0428	0.8122	0.0599
0.0381	0.0185	0.3927	0.0491	1.372	0.0687
0.0798	0.0280	0.5971	0.0547	1.715	0.0713
0.1719	0.0394				

## (151)

m <sub>0</sub>	m	E <sub>25</sub>	m <sub>0</sub>	m	E <sub>25</sub>
0.003	0.030	0.0344	0.03	0.3	0.0310
0.005	0.050	0.0337	0.1	1	0.0312
0.010	0.100	0.0321			

+Hg   HgCl   BaCl <sub>2</sub> (c <sub>1</sub> )   BaCl <sub>2</sub> (c <sub>2</sub> )   HgCl   Hg (46)					
c <sub>1</sub>	E <sub>20</sub> , c <sub>2</sub> = 0.1	E <sub>20</sub> , c <sub>2</sub> = 0.05	E <sub>20</sub> , c <sub>2</sub> = 0.02	E <sub>20</sub> , c <sub>2</sub> = 0.01	E <sub>20</sub> , c <sub>2</sub> = 0.005
0.05	0.0095				
0.02	0.0209	0.0117			
0.01	0.0324	0.0229	0.0091		
0.005	0.0436	0.0355	0.0209	0.0107	
0.002	0.0613	0.0475	0.0350	0.0233	0.0150
0.001	0.0716	0.0578	0.0706	0.0356	0.0248

+Ba <sub>1</sub> %Hg   BaCl <sub>2</sub> (c <sub>1</sub> )   KCl(2N)   BaCl <sub>2</sub> (0.005c)   Ba <sub>1</sub> %Hg					
c <sub>1</sub>	E <sub>20</sub> , c <sub>2</sub> = 0.01	E <sub>20</sub> , c <sub>2</sub> = 0.02	E <sub>20</sub> , c <sub>2</sub> = 0.0505	E <sub>20</sub> , c <sub>2</sub> = 0.103	
0.001	0.0071	0.0147	0.0263	0.0342	(46)

Ag | AgCl | BaCl<sub>2</sub>(0.5c) | Ba<sub>2</sub>Hg | BaCl<sub>2</sub>(0.1N), sucrose(y) | AgCl | Ag +  
 $x = 0.1$  and  $0.01\%$ ,  $y = 40\%$  and  $60\%$  by vol. of solution;  
 $25^\circ$  (38)

BaBr<sub>2</sub>

(A) Ag | AgBr | BaBr<sub>2</sub>(m) | Ba<sub>2</sub>Hg | BaBr<sub>2</sub>(m<sub>0</sub>) | AgBr | Ag +  
 (B) Ag | AgBr | BaBr<sub>2</sub>(m) | BaBr<sub>2</sub>(m<sub>0</sub>) | AgBr | Ag + (60)

m <sub>0</sub>	m	(A) E <sub>25</sub>	(B) E <sub>25</sub>
0.003	0.03	0.0774	0.0339
0.005	0.05	0.0764	0.0332
0.010	0.050	0.0527	0.0227
0.010	0.100	0.0744	0.0322
0.030	0.100	0.0390	0.0164
0.030	0.300	0.0759	0.0313
0.050	0.500	0.0782	0.0314
0.100	1.000	0.0822	0.0319

+Hg   HgBr   BaBr <sub>2</sub> (c <sub>1</sub> )   BaBr <sub>2</sub> (c <sub>2</sub> )   HgBr   Hg (46)						
c <sub>1</sub>	E <sub>20</sub> , c <sub>2</sub> = 0.1	E <sub>20</sub> , c <sub>2</sub> = 0.05	E <sub>20</sub> , c <sub>2</sub> = 0.02	E <sub>20</sub> , c <sub>2</sub> = 0.01	E <sub>20</sub> , c <sub>2</sub> = 0.005	E <sub>20</sub> , c <sub>2</sub> = 0.002
0.05	0.0095					
0.02	0.0238	0.0133				
0.01	0.0325	0.0220	0.0104			
0.005	0.0414	0.0340	0.0213	0.0093		
0.002	0.0582	0.0486	0.0342	0.0233	0.0120	
0.001	0.0707	0.0627	0.0509	0.0398	0.0272	0.0126

+Ba <sub>1</sub> %Hg   BaBr <sub>2</sub> (c)   KCl(2N)   BaBr <sub>2</sub> (0.01N)   Ba <sub>1</sub> %Hg					
c	0.0201	0.0505	0.103		
E <sub>20</sub>	0.0084	0.0169	0.0259		(46)

## LiOH

H <sub>2</sub>   LiOH(m)   Li <sub>2</sub> Hg   LiOH(m <sub>0</sub> )   H <sub>2</sub> + (86)					
m	m <sub>0</sub>	E <sub>25</sub>	m	m <sub>0</sub>	E <sub>25</sub>
0.0505	0.0101	0.0761	0.553	0.1006	0.0765
0.1008	0.0101	0.1088	0.611	0.1011	0.0808
0.1038	0.0103	0.1084	1.063	0.1006	0.1069
0.0978	0.0235	0.0669	1.812	0.0997	0.1307
0.242	0.1013	0.0396	2.386	0.1043	0.1412
0.346	0.0993	0.0566	2.577	0.1051	0.1438
0.432	0.0993	0.0664	3.926	0.1051	0.1651

H <sub>2</sub>   LiOH, LiCl   Li <sub>2</sub> Hg   LiOH   H <sub>2</sub> +			
LiOH	LiCl	t	Lit.
m = 0.01	m = 0.0 to 8.36	25	(86)
m = 0.1	m = 0.0 to 8.48	25	(86)

## LiCl

Ag   AgCl   LiCl(m <sub>1</sub> )   Li <sub>2</sub> Hg   LiCl(m <sub>2</sub> )   AgCl   Ag +					
m <sub>1</sub>	m <sub>2</sub>	E <sub>25</sub>	m <sub>1</sub>	m <sub>2</sub>	E <sub>25</sub>
3.0	0.3	0.14170	0.1	0.01	0.11055
1.0	0.1	0.11650	0.03	0.003	0.11275
0.3	0.1	0.05370	0.01	0.001	0.1139
0.3	0.03	0.11117			(130)

Ag   AgCl   LiCl(m <sub>1</sub> )   LiCl(m <sub>2</sub> )   AgCl   Ag +					
m <sub>1</sub>	m <sub>2</sub>	E <sub>25</sub>	m <sub>1</sub>	m <sub>2</sub>	E <sub>25</sub>
3.0	0.3	0.03957	0.1	0.01	0.03589
1.0	0.1	0.03543	0.03	0.003	0.03560
0.3	0.1	0.01642	0.01	0.001	0.03906
0.3	0.03	0.03521			(130)



## LiCl.—(Continued)

Ag | AgCl | LiCl( $c_1$ ), LiNO<sub>3</sub>( $c_2$ ) | LiNO<sub>3</sub>( $c_2$ ), LiCl(0.002 $c$ ) | AgCl | Ag +  
Values of  $E_{18}$  (157)

$c_1 \backslash c_2$	0.005	0.01	0.02	0.04
0.01	0.0341	0.0362	0.0371	0.0368
0.02	0.0466	0.0510	0.0533	0.0531
0.04	0.0584	0.0628	0.0656	0.0682

Li<sub>2</sub>SO<sub>4</sub>

Hg | Hg<sub>2</sub>SO<sub>4</sub> | Li<sub>2</sub>SO<sub>4</sub>( $m$ ) | Li<sub>2</sub>Hg | Li<sub>2</sub>SO<sub>4</sub>(0.05 $m$ ) | Hg<sub>2</sub>SO<sub>4</sub> | Hg + (7)

$m$	$E_{25}$	$m$	$E_{25}$	$m$	$E_{25}$
0.025	-0.0205	0.495	0.0684	1.447	0.1041
0.125	0.0274	0.979	0.0890	1.903	0.1143
0.249	0.0481				

## NaOH

H<sub>2</sub> | NaOH( $m$ ) | Na<sub>2</sub>Hg | NaOH( $m_0$ ) | H<sub>2</sub> + (75)

$m$	$m_0$	$E_{25}$	$m$	$m_0$	$E_{25}$
0.01011	0.00530	0.0315	0.3975	0.00995	0.1762
0.0202	0.01001	0.0338	0.807	0.01006	0.2103
0.0526	0.01000	0.0795	1.020	0.01016	0.2221
0.1047	0.00998	0.1116	1.517	0.01003	0.2459
0.1081	0.00984	0.1142	2.024	0.01014	0.2630
0.1934	0.00997	0.1416	3.100	0.01012	0.2926

H<sub>2</sub> | NaOH, NaX | Na<sub>2</sub>Hg | NaOH | H<sub>2</sub> +

NaOH	NaX	$t$	Lit.
$m = 0.01$ and $0.1$	NaCl, $m = 0$ to $3.1$	25	(76)
$m = 0.1$	NaBr, $m = 0$ to $3.1$	25	(84)

H<sub>2</sub> | NaOH, Na<sub>2</sub>SO<sub>4</sub> | Na<sub>2</sub>Hg | NaOH | H<sub>2</sub> +

NaOH	Na <sub>2</sub> SO <sub>4</sub>	$t$	Lit.
$m = 0.01$ and $0.1$	$c = 0.0$ to $2.5$	25	(7)

Hg | HgO | NaOH(0.235 $c$ ) | NaOH(0.03 $c$ ) | HgO | Hg +  
 $E_{18} = 0.0178$  (141)

## NaCl

Na<sub>0.139</sub>%Hg | NaCl( $c$ ) | HgCl | Hg + (8)

$c$	$m$	$E_{18}$	$E_{25}$
5.41	6.12	2.0281	2.0283
3.0	3.196	2.0770	2.0784
1.0	1.022	2.1398	2.1430
0.5	0.5034	2.1724	2.1769
0.1	0.1003	2.2466	2.2527
0.02	0.02003	2.2306	2.3267
0.01	0.01001	2.3520	2.3585

Ag | AgCl | NaCl( $c$ ) | NaCl(0.001674 $c$ ) | AgCl | Ag +

$c$ .....	0.03344	0.01673	0.01117	0.008364	0.006686
$E_{18}$ .....	0.05614	0.04360	0.03608	0.03073	0.02652

 (92)

Ag | AgCl | NaCl( $c_1$ ) | NaCl( $c_2$ ) | AgCl | Ag +

$c_1$ .....	0.04972	0.03973	0.02985	0.01985
$c_2$ .....	0.01984	0.01984	0.009909	0.009909
$E_{18}$ .....	0.01648	0.01232	0.02019	0.01257

 (93)

Hg | HgCl | NaCl( $c_1$ ) | NaCl( $c_2$ ) | HgCl | Hg +

$c_2 = 0.1$	$c_1$ ...	0.3	0.5	1	2	3
	$E_{25}$ ...	0.01991	0.02912	0.04202	0.05611	0.06530

 (73)
  

$c_1 = 6.12$ satd.	$c_2$ .....	1.0	0.1
	$E_{25}$ .....	0.0413	0.0831

 (142)

Ag | AgCl | NaCl( $c_1$ ), NaNO<sub>3</sub>( $2c$ ) | NaNO<sub>3</sub>( $2c$ ), NaCl( $c_2$ ) | AgCl | Ag +

$c_1$	$c_2$	$E_{20}$	Lit.
0.1001	0.01011	0.05776	(29)
0.01011	0.001110	0.05591	

## NaBr

Ag | AgBr | NaBr( $m$ ) | Na<sub>2</sub>Hg | NaBr(0.1 $m$ ) | AgBr | Ag + (81)

$m$	$E_{25}$	$m$	$E_{25}$	$m$	$E_{25}$
0.03	-0.0572	0.5	0.0773	2	0.1508
0.05	-0.0327	1	0.1123	2.5	0.1659
0.3	0.0524	1.5	0.1345	3	0.1779

Hg | HgBr | NaBr(0.125 $c$ ) | NaBr(0.0125 $c$ ) | HgBr | Hg +  
 $E_{18} = 0.0417$  (141)

## NaI

Ag | AgI | NaI( $m$ ) | Na<sub>2</sub>Hg | NaI(0.1 $m$ ) | AgI | Ag + (81)

$m$	$E_{25}$	$m$	$E_{25}$	$m$	$E_{25}$
0.03	-0.0572	0.5	0.0786	1	0.1147
0.3	0.0537				

Na<sub>2</sub>SO<sub>4</sub>

Hg | Hg<sub>2</sub>SO<sub>4</sub> | Na<sub>2</sub>SO<sub>4</sub>( $m$ ) | Na<sub>2</sub>Hg | Na<sub>2</sub>SO<sub>4</sub>(0.05 $m$ ) | Hg<sub>2</sub>SO<sub>4</sub> | Hg + (7)

$m$	$E_{25}$	$m$	$E_{25}$	$m$	$E_{25}$
0.025	-0.0202	0.495	0.0634	1.438	0.0909
0.125	0.0255	0.975	0.0809	1.882	0.0961
0.249	0.0452				

## KOH

H<sub>2</sub> | KOH( $c_1$ ) | K<sub>2</sub>Hg | KOH( $c_2$ ) | H<sub>2</sub> + (99)

$c_1$	$c_2$	$E_{25}$	$c_1$	$c_2$	$E_{25}$
3.000	0.2915	0.1416	0.300	0.0299	0.1110
2.955	0.2963	0.1395	0.0992	0.00989	0.1110
0.992	0.0996	0.1172	0.0996	0.00984	0.1110
0.995	0.0992	0.1170	0.0288	0.00286	0.1120
0.992	0.0996	0.1169	0.0299	0.00293	0.1130
0.300	0.0998	0.05361	0.0100	0.000991	0.1147
0.300	0.1000	0.05345	0.0100	0.001000	0.1149
0.2963	0.0282	0.1138			

H<sub>2</sub> | KOH( $m_1$ ) | KOH( $m_2$ ) | H<sub>2</sub> + (100)

$m_1$	$m_2$	$E_{25}$	$m_1$	$m_2$	$E_{25}$
3.0	0.3	0.03683	0.3	0.03	0.02916
1.0	0.1	0.03104	0.1	0.01	0.03465
0.3	0.1	0.01424			

H<sub>2</sub> | KOH, K<sub>2</sub>SO<sub>4</sub> | K<sub>2</sub>Hg | KOH | H<sub>2</sub> + (7)

KOH,  $m = 0.01$  and  $0.1$ ; K<sub>2</sub>SO<sub>4</sub>,  $c = 0.0$  to  $0.625$ ; 25°C

H<sub>2</sub> | KOH, KX | K<sub>2</sub>Hg | KOH | H<sub>2</sub> +

KOH	KX	$t$ , °C	Lit.
$m = 0.01$ and $0.1$ .....	KCl, $m = 0.0$ to $3.1$	25	(77)
	KBr, $m = 0.0$ to $3.1$	25	(84)
$m = 0.1$ .....	KI, $m = 0.0$ to $3.1$	25	(84)

## KCl

Ag | AgCl | KCl( $c_1$ ) | K<sub>2</sub>Hg | KCl( $c_2$ ) | AgCl | Ag + (131)

$c_1$	$c_2$	$x$	$E_{25}$	$c_1$	$c_2$	$x$	$E_{25}$
0.5	0.05	0.02	0.10735	0.1	0.01	0.002	0.10900
0.5	0.05	0.002	0.10745	0.05	0.005	0.004	0.11085
0.1	0.01	0.004	0.10885	0.05	0.005	0.002	0.11085



## KCl.—(Continued)

Ag   AgCl   KCl( $c_1$ )   KCl( $c_2$ )   AgCl   Ag + ( <sup>92</sup> )					
$c_1$	$c_2$	$E_{18}$	$c_1$	$c_2$	$E_{18}$
0.03347	0.003347	0.05403	0.01669	0.001670	0.05424
0.01669	0.003347	0.03806	0.01114	0.001670	0.04497
0.01117	0.003347	0.02856	0.008329	0.001670	0.03844
0.008350	0.003347	0.02175	0.006700	0.001670	0.03330
0.006696	0.003347	0.01643	0.005569	0.001670	0.02895
0.03349	0.001670	0.07028			

$c_1$	$c_2$	$E_{25}$ ( <sup>131</sup> )	$c_1$	$c_2$	$E_{18}$ ( <sup>93</sup> )
0.5	0.05	0.05357	0.04985	0.01969	0.02106
0.1	0.01	0.05400	0.03995	0.01969	0.01644
0.05	0.005	0.05473	0.03000	0.009924	0.02546
0.01	0.001	0.0560	0.01992	0.009924	0.01614

Ag   AgCl   KCl(satd.)   KCl(0.2775c)   AgCl   Ag +							
$t, ^\circ\text{C.}$	0	14.2	30.1	45.2	60.2	76.0	90.3
$E_{25}$	0.0562	0.0637	0.0712	0.0782	0.0850	0.0917	0.0968

(<sup>27</sup>)

Hg | HgCl | KCl( $c_1$ ) | KCl(0.1c) | HgCl | Hg + (<sup>72</sup>); cf. (<sup>62</sup>).

$c_1$	$E_{25}$	$c_1$	$E_{25}$
0.160	0.01044	0.700	0.04443
0.200	0.01536	1.000	0.05287
0.220	0.01802	1.300	0.05910
0.300	0.02475	1.900	0.06843
0.340	0.02785	2.500	0.07572
0.500	0.03637	3.100	0.08165

Ag   AgCl   KCl(0.5c)   K <sub>2</sub> Hg   KCl(0.1c), sucrose(C)   AgCl   Ag +			
$C, \text{g/100 cm}^3$	$E_{25}$ ( <sup>38</sup> )	$C, \text{g/100 cm}^3$	$E_{25}$ ( <sup>38</sup> )
0	0.0740	40	0.0600
10	0.0706	50	0.0556
20	0.0674	60	0.0510
30	0.0642	70	0.0455

Ag   AgCl   KCl(0.5c)   KCl(0.1c), sucrose(C)   AgCl   Ag +							
First cell ( <sup>39</sup> )				Second cell ( <sup>39</sup> )			
$C^*$	$E_{25}$	$C^*$	$E_{25}$	$C^*$	$E_{25}$	$C^*$	$E_{25}$
0	0.0368	40	0.0300	0	0.0368	40	0.0435
10	0.0352	50	0.0281	10	0.0384	50	0.0454
20	0.0335	60	0.0261	20	0.0401	60	0.0474
30	0.0316	70	0.0240	30	0.0418	70	0.0496

\* g/100 cm<sup>3</sup>.

Ag   AgCl   KCl( $c_1$ ), KNO <sub>3</sub> ( $c_2$ )   KNO <sub>3</sub> ( $c_2$ ), KCl(0.002c)   AgCl   Ag +					
Values of $E_{25}$ ( <sup>157</sup> , <sup>158</sup> )					
$c_1 \backslash c_2$	0.005	0.01	0.02	0.04	
0.01	0.0392	0.0401	0.0391	0.0392	
0.02	0.0544	0.0573	0.0567	0.0559	
0.04	0.0712	0.0724	0.0723	0.0725	

Ag   AgCl   KCl( $c_1$ ), KNO <sub>3</sub> (2c)   KNO <sub>3</sub> (2c), KCl( $c_2$ )   AgCl   Ag +				
$c_1$	0.2	0.1	0.05	
$c_2$	0.1	0.05	0.025	
$E_{25}$	0.01744	0.01757	0.01746	( <sup>29</sup> )

## KBr

Ag   AgBr   KBr( $m$ )   K <sub>2</sub> Hg   KBr(0.1m)   AgBr   Ag + ( <sup>81</sup> )					
$m$	$E_{25}$	$m$	$E_{25}$	$m$	$E_{25}$
0.05	-0.0324	1	0.1068	2	0.1410
0.3	0.0513	1.5	0.1266	2.5	0.1531
0.5	0.0746				

K<sub>2</sub>Hg | KBr( $c$ ) | AgBr | Ag + (<sup>152</sup>) $c = 0.001$  to 2.5; 25, 30, 35°CAg | AgBr | KBr( $m_1$ ) | KBr( $m_2$ ) | AgBr | Ag + (<sup>152</sup>) $m_1 = 0.01$  to 2.8;  $m_2 = 0.001$  to 0.25; 25, 30, 35°C+ Hg | HgBr | KBr( $c_1$ ) | KBr( $c_2$ ) | HgBr | Hg (<sup>45</sup>)

$c_1$	$c_2$	$E_{18}$	$c_1$	$c_2$	$E_{18}$
0.00202	0.00996	0.0391	0.00996	0.02004	0.0161
0.00202	0.02004	0.0569	0.00996	0.4004	0.0851
0.00202	0.04004	0.0717	0.02004	0.4004	0.0161
0.00202	0.1204	0.0971	0.04004	0.1204	0.0251
0.00202	0.4004	0.1242	0.1204	0.4004	0.0272

## KI

Ag | AgI | KI( $m$ ) | K<sub>2</sub>Hg | KI(0.1m) | AgI | Ag + (<sup>81</sup>)

$m$	$E_{25}$	$m$	$E_{25}$	$m$	$E_{25}$
0.3	0.0522	1	0.1092	2	0.1447
0.5	0.0758				

Ag | AgI | KI( $c_1$ ) | KI( $c_2$ ) | AgI | Ag +

$c_1$	$c_2$	$E$	Lit.
0.1	0.01	0.0536	
0.01	0.001	0.0552	( <sup>109</sup> )

Ag | AgI | KI( $c_1$ ) in H<sub>2</sub>O | KI(0.001c) in C<sub>2</sub>H<sub>5</sub>OH | AgI | Ag (<sup>109</sup>)

$c_1$	$E_{25}$	$c_1$	$E_{25}$
0.001	0.080	0.02	$\pm 0.000$
0.0025	0.049	0.04	-0.016
0.005	0.034	0.06	-0.027
0.0075	0.025	0.08	-0.033
0.01	0.017	0.10	-0.041

K<sub>2</sub>SO<sub>4</sub>Hg | Hg<sub>2</sub>SO<sub>4</sub> | K<sub>2</sub>SO<sub>4</sub>( $m$ ) | K<sub>2</sub>Hg | K<sub>2</sub>SO<sub>4</sub>(0.05m) | Hg<sub>2</sub>SO<sub>4</sub> | Hg + (<sup>7</sup>)

$m$	$E_{25}$	$m$	$E_{25}$	$m$	$E_{25}$
0.025	-0.0198	0.248	0.0420	0.621	0.0654
0.125	0.0241	0.494	0.0601		

KAg(CN)<sub>2</sub>Ag | KAg(CN)<sub>2</sub>( $c_1$ ), KCN( $c_2$ ) | KCN( $c_3$ ) | KAg(CN)<sub>2</sub>( $c_4$ ) | Ag $c_1 = 0.05$  to 0.05;  $c_2$  and  $c_3 = 0.02$  to 1.0;  $c_4 = 0.025$  to 0.025; room temp. (<sup>18</sup>)

## NON-AQUEOUS SOLUTIONS

Solvent	Electrolyte	$t$	Lit.
NH <sub>3</sub>	Na	-33	( <sup>102</sup> )
CH <sub>3</sub> OH	HCl	25	( <sup>145</sup> )
CH <sub>3</sub> OH	AgNO <sub>3</sub>	25	( <sup>64</sup> )
CH <sub>3</sub> OH + H <sub>2</sub> O	AgNO <sub>3</sub>	0 and 25	( <sup>149</sup> )
CH <sub>3</sub> OH + H <sub>2</sub> O	NaOH	18	( <sup>179</sup> )
CH <sub>3</sub> OH + H <sub>2</sub> O	KCl	10 to 40	( <sup>26</sup> )
CH <sub>3</sub> OH + H <sub>2</sub> O	KBr	10 to 40	( <sup>26</sup> )
C <sub>2</sub> H <sub>5</sub> OH	HCl	25	( <sup>42</sup> , <sup>70</sup> , <sup>82</sup> , <sup>83</sup> , <sup>106</sup> )
C <sub>2</sub> H <sub>5</sub> OH	AgNO <sub>3</sub>	25	( <sup>11</sup> )
C <sub>2</sub> H <sub>5</sub> OH	LiCl	25	( <sup>49</sup> )
C <sub>2</sub> H <sub>5</sub> OH	NaOC <sub>2</sub> H <sub>5</sub>	25	( <sup>42</sup> )
C <sub>2</sub> H <sub>5</sub> OH	NaBr	25	( <sup>49</sup> )



## NON-AQUEOUS SOLUTIONS.—(Continued)

Solvent	Electrolyte	<i>t</i>	Lit.
C <sub>2</sub> H <sub>5</sub> OH + H <sub>2</sub> O	HCl	25	(82, 83)
C <sub>2</sub> H <sub>5</sub> OH + H <sub>2</sub> O	AgNO <sub>3</sub>	40	(103)
C <sub>2</sub> H <sub>5</sub> OH + H <sub>2</sub> O	AgNO <sub>3</sub>	0 and 25	(149)
C <sub>2</sub> H <sub>5</sub> OH + H <sub>2</sub> O	KCl	10 to 40	(26)
C <sub>2</sub> H <sub>5</sub> OH + H <sub>2</sub> O	KBr	10 to 40	(26)
C <sub>2</sub> H <sub>5</sub> OH + CH <sub>3</sub> OH	AgNO <sub>3</sub>	0 and 25	(149)
(CH <sub>3</sub> ) <sub>2</sub> CO	AgNO <sub>3</sub>	25	(64)
C <sub>2</sub> H <sub>5</sub> O <sub>2</sub> + H <sub>2</sub> O	HCl	25	(125, 126)
C <sub>2</sub> H <sub>5</sub> N	AgNO <sub>3</sub>	25	(64, 160)
C <sub>2</sub> H <sub>5</sub> N + H <sub>2</sub> O	AgNO <sub>3</sub>	25	(138)
C <sub>2</sub> H <sub>5</sub> N + CH <sub>3</sub> OH	AgNO <sub>3</sub>	25	(138)
C <sub>2</sub> H <sub>5</sub> N + C <sub>2</sub> H <sub>5</sub> OH	AgNO <sub>3</sub>	25	(138)
C <sub>2</sub> H <sub>5</sub> NH <sub>2</sub>	AgNO <sub>3</sub>	25	(64)
NaNO <sub>2</sub>	AgNO <sub>3</sub>	400	(68)

## II. CELLS WITH SALT BRIDGES

The calomel electrode is the reference electrode except as otherwise indicated; Ac = CH<sub>3</sub>COO, the acetate radical

## AQUEOUS SOLUTIONS

Cations, standard arrangement; *v.* Vol. III, p. viii

Solutes	<i>t</i> , °C	Lit.
H <sup>+</sup> (or OH <sup>-</sup> ), H <sub>2</sub> electrode		
HF	25	(184)
HCl	25	(165)
HCl(+glycerol)	25	(36)
HCl(+sucrose)	25, 35	(39, 137, 166)
HCl(+HAc)	25	(116)
HCl(+salts)	20, 25	(5, 23, 65, 71, 74, 78, 80, 135)
HCl(KHCO <sub>3</sub> + K <sub>2</sub> CO <sub>3</sub> + KCl)	25	(181)
HClO <sub>4</sub>	25	(170)
HBr(+salts)	16–18	(9, 153)
H <sub>2</sub> SO <sub>4</sub> (+sucrose)	20, 40	(94)
H <sub>2</sub> SO <sub>4</sub> (+salts)	19	(5, 7)
HNO <sub>3</sub> (+salts)	19	(5)
HAc(+NaAc)	18	(35, 182, 183)
HAc(+NaAc + NaCl + HCl)	18	(183)
HAc(+salts)	16	(161)
HAc(+sucrose)	35	(52, 116)
Palmitic acid + NaOH + NaCl	90	(129)
Na soaps	90	(129)
K soaps	90	(129)
NaOH	30	(58, 123)
NaOH(+glycerol)	25	(36)
NaOH(+sucrose)	35	(52)
NaOH(+salts)	25	(71, 78)
KOH(+salts)	25	(71, 78)
KH <sub>2</sub> PO <sub>4</sub> + K <sub>2</sub> HPO <sub>4</sub>	25	(34)
H <sup>+</sup> (or OH <sup>-</sup> ), Quinhydrone electrode		
HCl(+KCl)	18	(168, 169)
HCl(+MgSO <sub>4</sub> )	18	(169)
CHCl <sub>3</sub> CO <sub>2</sub> H	18	(169)
(+MgSO <sub>4</sub> )	18	(169)
(+CCl <sub>3</sub> HCO <sub>2</sub> Na)	18	(169)
(+KCl)	18	(169)
H <sup>+</sup> (or OH <sup>-</sup> ), Ag   Ag <sub>2</sub> O electrode		
Ba(OH) <sub>2</sub>	25	(2)
Sn <sup>++</sup> , Sn electrode		
Sn(NO <sub>3</sub> ) <sub>2</sub>	25	(159)

## II. CELLS WITH SALT BRIDGES.—(Continued)

Solutes	<i>t</i> , °C	Lit.
Pb <sup>++</sup> , Pb electrode		
Pb(ClO <sub>3</sub> ) <sub>2</sub> *	25	(112)
Pb(NO <sub>3</sub> ) <sub>2</sub> *	25	(40, 89, 90, 112, 159)
PbAc <sub>2</sub> *	25	(105)
In <sup>+++</sup> , In electrode		
InCl <sub>3</sub>	25	(178)
Tl <sup>+</sup> , Tl electrode		
TlOH	25	(4)
TlCl	25	(4)
TlCl(satd.)	0, 25	(95)
TlCl(satd.)	25†	(114)
Tl <sub>2</sub> SO <sub>4</sub>	25	(4)
TlNO <sub>3</sub>	17, 25	(4, 25)
Zn <sup>++</sup> , Zn electrode		
ZnCl <sub>2</sub> (+KCl)	Room	(105)
ZnSO <sub>4</sub>	25	(98)
ZnSO <sub>4</sub> (0.5N)	15–25†	(98)
ZnSO <sub>4</sub> (+Na <sub>2</sub> SO <sub>4</sub> )	Room	(105)
ZnAc <sub>2</sub> (+NaAc)	Room	(105)
Zn(CN) <sub>2</sub> (+KCN)	18	(175)
Cd <sup>++</sup> , Cd electrode		
CdCl <sub>2</sub>	Room	(105)
CdSO <sub>4</sub> (+Na <sub>2</sub> SO <sub>4</sub> )	Room	(105)
CdAc <sub>2</sub> (+NaAc)	25	(90)
Hg <sup>++</sup> , Hg electrode		
HgBr <sub>2</sub>	25	(172, 173)
HgI <sub>2</sub> (+KI)	25	(172, 173)
HgS(+Na <sub>2</sub> S)	25	(101)
Hg(NO <sub>3</sub> ) <sub>2</sub> (+KNO <sub>3</sub> )	25	(3)
Hg(CN) <sub>2</sub> (+KCN + KOH)	25	(148)
Cu <sup>++</sup> , Cu electrode		
CuSO <sub>4</sub> (+Na <sub>2</sub> SO <sub>4</sub> )	Room	(105)
CuSO <sub>4</sub> (+KNO <sub>3</sub> )	Room	(88)
Cu(NO <sub>3</sub> ) <sub>2</sub> (+KNO <sub>3</sub> )	Room	(105)
CuAc <sub>2</sub> (+NaAc)	Room	(105)
Cu(CN) <sub>2</sub> (+KCN)	18	(125)
Ag <sup>+</sup> , Ag electrode		
AgCl(+KCl)	25§	(55)
AgCl(+NaCl)	25§	
AgI(+KI)	Room	(17, 18)
Ag <sub>2</sub> SO <sub>4</sub> (+MgSO <sub>4</sub> )	20	(29)
AgNO <sub>2</sub> (+KNO <sub>3</sub> )	25	(3)
AgNO <sub>3</sub>	17	(25)
	25	(167)
	30	(111)
AgNO <sub>3</sub> (+KNO <sub>3</sub> )	20	(29)
AgAc	17	(25)
AgSCN(+KSCN)	Room§	(17, 18)
KAg(CN) <sub>2</sub> (+KCN)	Room§	(17, 18)
Ag <sub>2</sub> CO <sub>3</sub> (+KHCO <sub>3</sub> + K <sub>2</sub> CO <sub>3</sub> + KCl)	25	(181)
Co <sup>++</sup> , Co electrode		
CoCl <sub>2</sub> (+KCl)	Room	(105)
CoSO <sub>4</sub> (+Na <sub>2</sub> SO <sub>4</sub> )	Room	(105)
Ni <sup>++</sup> , Ni electrode		
NiCl <sub>2</sub>	20	(171)
NiSO <sub>4</sub>	Room	(171)
Ca <sup>++</sup> , Ca, Hg electrode		
CaCl <sub>2</sub>	21	(47)
CaI <sub>2</sub>	21	(47)



## II. CELLS WITH SALT BRIDGES.—(Continued)

Solutes	<i>t</i> , °C	Lit.	
Li <sup>+</sup> , Li amalgam electrode			
LiCl.....	22	(48)	
LiClO <sub>4</sub> .....	22	(48)	
Li <sub>2</sub> SO <sub>4</sub> .....	23	(48)	
Na <sup>+</sup> , Na amalgam electrode			
Na <sub>2</sub> SO <sub>4</sub> .....	18	(48)	
Anions			
Solutes	<i>t</i> , °C	Ref. electrode	Lit.
X <sup>-</sup> , Ag   AgX electrode (X = halogen)			
HCl(+sucrose).....	25	Ag   AgCl	(39)
AlBr <sub>3</sub> .....	25	Ag   AgNO <sub>3</sub> (0.1 <i>N</i> )	(96)
KI.....	25	Hg   HgCl	(109)
KBr.....	25	Ag   AgBr	(45)
I <sup>-</sup> , I <sub>2</sub> electrode			
KI.....	25	Hg   HgCl	(95)
KI + I <sub>2</sub> .....	25	Hg   HgCl	(134)
CdI <sub>2</sub> + I <sub>2</sub> .....	25	I <sub>2</sub> , KI	(180)
I <sup>-</sup> , Pb   PbI <sub>2</sub> electrode			
KI.....	25	Hg   HgCl	(113)
IO <sub>3</sub> <sup>-</sup> , Ag   AgIO <sub>3</sub> electrode			
KIO <sub>3</sub> .....	25, 60	Ag   AgNO <sub>3</sub>	(162)
CO <sub>3</sub> <sup>2-</sup> , Ag   Ag <sub>2</sub> CO <sub>3</sub> electrode			
Na <sub>2</sub> CO <sub>3</sub> .....	25	Hg   HgCl	(174)
C <sub>2</sub> O <sub>4</sub> <sup>2-</sup> , Ag   Ag <sub>2</sub> C <sub>2</sub> O <sub>4</sub> electrode			
K <sub>2</sub> C <sub>2</sub> O <sub>4</sub> .....	25	Hg   HgCl	(167)
KHC <sub>2</sub> O <sub>4</sub> .....	25	Hg   HgCl	(167)
KH <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub> .....	25	Hg   HgCl	(167)

## Molecules

Cl<sub>2</sub>, Cl<sub>2</sub> electrode

Cl<sub>2</sub> at various concentrations in 0.5N HCl against 0.1N calomel electrode (177).

\* Also + the corresponding alkali metal salts.

† Tl | TlNO<sub>3</sub>, ref. electrode.  
‡ Hg | Hg<sub>2</sub>SO<sub>4</sub>, ref. electrode.  
|| Ag | AgCl, ref. electrode.  
§ Ag | AgNO<sub>3</sub>, ref. electrode.

## NON-AQUEOUS SOLUTIONS

## Reference electrode, Hg | HgCl

H<sup>+</sup>, H<sub>2</sub> electrode

HCl(+KCl) at 25° in C<sub>2</sub>H<sub>5</sub>OH (and + H<sub>2</sub>O) (14, 136).

Ag<sup>+</sup>, Ag electrode

AgNO<sub>3</sub> at 25° in mixtures of H<sub>2</sub>O with CH<sub>3</sub>OH, C<sub>2</sub>H<sub>5</sub>OH, and pyridine and in CH<sub>3</sub>OH + pyridine, and C<sub>2</sub>H<sub>5</sub>OH + pyridine (138, 149).

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## POTENTIALS OF ELECTROCHEMICAL REACTIONS

ROSCOE H. GERKE

The potential,  $E$ , of an electrochemical reaction is given by

$$E = E_0 - \frac{0.05915}{N} \log_{10} \frac{(A_P)^x}{(A_R)^y}$$

where  $N$  is the number of faradays of electricity in the equation of the reaction;  $A_P$ , resp.  $A_R$ , the activities of the products (resp. reactants) and  $x$  and  $y$  the corresponding coefficients in the electrochemical equation. In the following tables are recorded the values of  $E$  for the following conditions:

All molecular and ion species whose concentrations are not fixed by the nature of the phases present as shown by the reaction given are at the concentration at which their molal activities are unity (i.e., "activity molal"), the activity coefficients being those given by Lewis and Randall (43); except for HCl, for which *v.* (85). All gases are present at  $p = 1A_n$ . For further details, *v.* (23).

In all cases the electrochemical reaction tends to take place from left to right as written, when opposed to an "activity-molal" hydrogen electrode. The increase in free energy,  $\Delta F$ , attending the reaction is given by  $\Delta F = -NFE$  where  $F$  is the value of the faraday.

The electromotive force of a cell composed of two electrodes with liquid junction potentials eliminated is equal to the difference between the potentials for electrochemical reactions of the same pole sign and is equal to the sum of the potentials for reactions of different pole signs.

## Potentials of Electrochemical Reactions at 25°C

1. The electrode which is in equilibrium with respect to the electrochemical reaction is charged negatively (i.e., pole sign is -).

Reaction	Volt	Lit.
$\text{Li(s)} = \text{Li}^+ + e$	2.9595	(43)
$\text{Rb(s)} = \text{Rb}^+ + e$	2.9259	(43)
$\text{K(s)} = \text{K}^+ + e$	2.9241	(43)
$\text{Ca(s)} = \text{Ca}^{++} + 2e$	2.763	(16)
$\text{Na(s)} = \text{Na}^+ + e$	2.7146	(43)
$\text{BaHg} = \text{Ba}^{++} + 2e$	1.5700	(14)
$\text{NaHg} + (\text{Cl}^- \text{ in NaCl satd.}) = \text{NaCl(s)} + e$	1.8378	(13)
$\text{SrHg} = \text{Sr}^{++} + 2e$	1.7932	(14)
$\text{AlHg} + 3\text{OH}^- = \text{Al(OH)}_3(\text{s}) + 3e$	1.62	(31)
$\text{Zn(s)} + 2\text{OH}^- = \text{ZnO(s)} + \text{H}_2\text{O(l)}$	1.2483	(81)
$\frac{1}{2}\text{H}_2(\text{g}) + \text{OH}^- = \text{H}_2\text{O(l)} + e$	0.8295	(43)
$\text{ZnHg} + (\text{SO}_4^{--} \text{ in ZnSO}_4 \cdot 7\text{H}_2\text{O satd.}) = \text{ZnSO}_4 \cdot 7\text{H}_2\text{O(s)} + 2e$	.7993	(73)
$\text{Ti(s)} + \text{I}^- = \text{TiI(s)} + e$	.7715	(37)
$\text{CdHg} + 2\text{OH}^- = \text{Cd(OH)}_2(\text{s}) + 2e$	.761	(47)
$\text{Zn(s)} = \text{Zn}^{++} + 2e$	.7618	(43)
$\text{CdHg} + 2\text{OH}^- = \text{CdO(s)} + \text{H}_2\text{O(l)} + 2e$	.726	(47)
$\text{TiHg} + \text{Br}^- = \text{TiBr(s)} + e$	.6058	(41)
$\text{Pb(s)} + 2\text{OH}^- = \text{PbO(s}_{\text{red}}) + \text{H}_2\text{O(l)} + 2e$	.5786	(4, 71)
$\text{Pb(s)} + 2\text{OH}^- = \text{PbO(s)} + \text{H}_2\text{O(l)} + 2e$	.576	(21)
$\text{Pb(s)} + 2\text{OH}^- = \text{PbO(s}_{\text{yellow}}) + \text{H}_2\text{O(l)} + 2e$	.575	(4)
$\text{PbHg} + 2\text{OH}^- = \text{Pb(OH)}_2(\text{s}) + 2e$	.568	(24)
$\text{Cr(s)} = \text{Cr}^{++} + 2e$	.557	(28)
$\text{TiHg} + \text{Cl}^- = \text{TiCl(s)} + e$	.5545	(22)
$\text{CdHg} + (2\text{I}^- \text{ in CdI}_2 \text{ satd.}) = \text{CdI}_2(\text{s}) + 2e$	.4588	(55, 77)
$\text{Fe(s)} = \text{Fe}^{++} + 2e$	.441	(43)
$\text{TiHg} + \text{SO}_4^{--} = \text{Ti}_2\text{SO}_4(\text{s}) + 2e$	.4360	(33)
$\text{CdHg} + (\text{SO}_4^{--} \text{ in CdSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O satd.}) = \text{CdSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O(s)} + 2e$	.4346	(55)

Reaction	Volt	Lit.
$\text{CdHg} + (2\text{Br}^- \text{ in CdBr}_2 \cdot 4\text{H}_2\text{O satd.}) = \text{CdBr}_2 \cdot 4\text{H}_2\text{O(s)} + 2e$	0.4182	(56)
$\text{CdHg} + (2\text{Cl}^- \text{ in CdCl}_2 \text{ satd.}) = \text{CdCl}_2(\text{s}) + 2e$	.4034	(55)
$\text{Cr}^{++} = \text{Cr}^{+++} + e$	.400	(20, 28)
$\text{Cd(s)} = \text{Cd}^{++} + 2e$	.4013	(43)
$\text{PbHg} + 2\text{I}^- = \text{PbI}_2(\text{s}) + 2e$	.3591	(22)
$2\text{Cu(s)} + 2\text{OH}^- = \text{Cu}_2\text{O(s)} + \text{H}_2\text{O(l)} + 2e$	.344	(1)
$\text{PbHg} + \text{SO}_4^{--} = \text{PbSO}_4(\text{s}) + 2e$	.3438	(30)
$\text{TiHg} = \text{Ti}^+ + e$	.3360	(43)
$\text{PbHg} + 2\text{Cl}^- = \text{PbCl}_2(\text{s}) + 2e$	.2623	(22)
$\text{Cu(s)} + \text{H}_2\text{S(g)} = \text{CuS(s)} + 2\text{H}^+ + 2e$	.259	(39)
$\text{Ni(s)} = \text{Ni}^{++} + 2e$	.231	(79)
$\text{Sb(s)} + \text{H}_2\text{O(l)} = \text{SbO}^+ + 2\text{H}^+ + 3e$	.212	(69)
$\text{VSO}_4 + \text{H}_2\text{O(l)} = \frac{1}{2}(\text{VO})_2\text{SO}_4 + 2\text{H}^+ + \frac{1}{2}\text{SO}_4^{--} + e$	.21	(65)
$\text{Cu}_2\text{O(s)} + 2\text{OH}^- = 2\text{CuO(s}_{\text{red}}) + \text{H}_2\text{O(l)} + 2e$	.154	(2)
$\text{Ag(s)} + \text{I}^- = \text{AgI(s)} + e$	.151	(22, 52, 74)
$\text{Sn(s)} = \text{Sn}^{++} + 2e$	.136	(43)
$\text{Pb(s)} = \text{Pb}^{++} + 2e$	.122	(43)
$\text{Cu}_2\text{O(s)} + 2\text{OH}^- + \text{H}_2\text{O(l)} = 2\text{Cu(OH)}_2(\text{s}) + 2e$	.082	(1)
$2\text{Hg(l)} + 2\text{I}^- = \text{Hg}_2\text{I}_2(\text{s}) + 2e$	.0416	(77)
$2\text{Ag(s)} + \text{H}_2\text{S(g)} = \text{Ag}_2\text{S(s)} + 2\text{H}^+ + 2e$	.0366	(53)
$\frac{1}{2}\text{H}_2(\text{g}) = \text{H}^+ + e$	.0000	
2. The electrode which is in equilibrium with respect to the electrochemical reaction is charged positively (i.e., pole sign is +).		
$\frac{1}{2}\text{H}_2(\text{g}) = \text{H}^+ + e$	0.0000	
$\text{Ti(SO}_4)_2 + e = \text{Ti}^{+++} + 2\text{SO}_4^{--}$	.04	(15)
$\text{PbS(s)} + 2\text{H}^+ + 2e = \text{Pb(s)} + \text{H}_2\text{S(g)}$	.070	(39)
$\text{AgBr(s)} + e = \text{Ag(s)} + \text{Br}^-$	.0734	(45)
$\text{HgO(s}_{\text{red}}) + \text{H}_2\text{O(l)} + 2e = \text{Hg(l)} + 2\text{OH}^-$	.0969	(21, 43)
$\text{HgO(s}_{\text{yellow}}) + \text{H}_2\text{O(l)} + 2e = \text{Hg(l)} + 2\text{OH}^-$	.0976	(9)
$\text{CuCl(s)} + e = \text{Cu(s)} + \text{Cl}^-$	.1287	(51, 52)
$\text{Hg}_2\text{Br}_2(\text{s}) + 2e = 2\text{Hg(l)} + 2\text{Br}^-$	.1385	(25)
$\text{Sb}_2\text{O}_3(\text{s}) + 6\text{H}^+ + 6e = 2\text{Sb(s)} + 3\text{H}_2\text{O(l)}$	.1445	(69)
$\text{BiOCl(s)} + 2\text{H}^+ + 3e = \text{Bi(s)} + \text{Cl}^- + \text{H}_2\text{O(l)}$	.1588	(35, 51)
$\text{AgCl(s)} + e = \text{Ag(s)} + \text{Cl}^-$	.2221	(22, 50, 52, 68, 85)
$\text{As}_2\text{O}_3(\text{s}) + 6\text{H}^+ + 6e = 2\text{As(s)} + 3\text{H}_2\text{O(l)}$	.2340	(70)
$\text{HAsO}_2 + 3\text{H}^+ + 3e = \text{As(s)} + 2\text{H}_2\text{O(l)}$	.2375	(70)
$\text{Hg}_2\text{Cl}_2(\text{s}) + 2e = 2\text{Hg(l)} + 2\text{Cl}^-$	.2676	(43, 85)
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O(s)} + 2e = \text{CuHg} + (\text{SO}_4^{--} \text{ in CuSO}_4 \cdot 5\text{H}_2\text{O satd.})$	.2684	(54, 57)
$\text{PbO}_2(\text{s}) + \text{H}_2\text{O(l)} + 2e = \text{PbO(s)} + 2\text{OH}^-$	.27	(27)
Normal calomel electrode	.2805	(85)
$\text{VOSO}_4 + e = \frac{1}{2}(\text{VO})_2\text{SO}_4 + \frac{1}{2}\text{SO}_4^{--}$	.30	(65)
Decinormal calomel electrode	.3334	(85)
$\text{Cu}^{++} + 2e = \text{Cu(s)}$	.3441	(42)
$\text{Cu}^{++} + 2e = \text{Cu(satd. amalgam)}$	.3495	(49)
$\text{UO}_2\text{SO}_4 + 4\text{H}^+ + \text{SO}_4^{--} + 2e = \text{U(SO}_4)_2 + 2\text{H}_2\text{O(l)}$	.358	(46)



Reaction	Volt	Lit.
$\text{Ti}^{+++} + e = \text{Ti}^{++}$	0.37	(19)
$\text{Cu}^{++} + 2\text{Cl}^- + e = \text{CuCl}_2^-$	.455	(8)
$\text{W}(\text{CN})_8^{--} + e = \text{W}(\text{CN})_8^{--}$	.485	(11, 12)
$\text{K}_3\text{Fe}(\text{CN})_6 + \text{K}^+ + e = \text{K}_4\text{Fe}(\text{CN})_6$	.4866	(44)
$\text{Ag}_2\text{CO}_3(\text{s}) + 2e = 2\text{Ag}(\text{s}) + \text{CO}_3^{--}$	.500	(72)
$\frac{1}{2}\text{I}_2(\text{s}) + e = \text{I}^-$	.5345	(43, 80)
$\text{H}_3\text{AsO}_4 + 2\text{H}^+ + 2e = \text{H}_3\text{AsO}_3 + \text{H}_2\text{O}$	.574	(17)
$\text{Hg}_2\text{SO}_4(\text{s}) + 2e = 2\text{Hg}(\text{l}) + \text{SO}_4^{--}$	.6213	(43)
$\text{MnO}_4^- + e = \text{MnO}_4^{--}$	.664	(66)
$\text{AgBrO}_3(\text{s}) + e = \text{Ag}(\text{s}) + \text{BrO}_3^-$	.680	(59)
$\text{PtCl}_4^- + 2e = \text{PtCl}_2 + 2\text{Cl}^-$	.717	(48)
$\text{Fe}^{+++} + e = \text{Fe}^{++}$	.7477	(50, 84)
$\text{Ag}^+ + e = \text{Ag}(\text{s})$	.7978	(43)
$\text{Hg}_2^{++} + 2e = 2\text{Hg}(\text{l})$	.7986	(43)
$\text{Mo}(\text{CN})_8^{--} + e = \text{Mo}(\text{CN})_8^{--}$	.820	(11, 12)
$[\text{Pt}(\text{CN})_4\text{Cl}_2]^- + 2e = [\text{Pt}(\text{CN})_4]^- + 2\text{Cl}^-$	.879	(87)
$\frac{1}{2}\text{Hg}_2^{++} + e = \text{Hg}^{++}$	.9011	(83)
$\text{HVO}_3 + \text{H}_2\text{SO}_4 + e = \text{VOSO}_4 + 2\text{H}_2\text{O}(\text{l})$	.92	(65)
$\frac{1}{2}\text{Br}_2(\text{l}) + e = \text{Br}^-$	1.0648	(43)
$\text{IO}_3^- + 6\text{H}^+ + 5e = \frac{1}{2}\text{I}_2(\text{s}) + 3\text{H}_2\text{O}(\text{l})$	1.197	(67)
$\text{Ti}^{+++} + 2e = \text{Ti}^{+}$	1.211	(29)
$\text{Sn}^{++++} + 2e = \text{Sn}^{++}$	1.256	(18)
$\text{MnO}_2(\text{s}) + 4\text{H}^+ + 2e = \text{Mn}^{++} + 2\text{H}_2\text{O}(\text{l})$	1.332	(75)
$\frac{1}{2}\text{Cl}_2(\text{g}) + e = \text{Cl}^-$	1.3583	(22, 43)
$\text{Au}^{+++} + 3e = \text{Au}(\text{s})$	1.36	(36)
$\text{Au}_2\text{O}_3(\text{s}) + 6\text{H}^+ + 6e = 2\text{Au}(\text{s}) + 3\text{H}_2\text{O}(\text{l})$	1.363	(7, 26)
$\text{BrO}_3^- + 6\text{H}^+ + 5e = \frac{1}{2}\text{Br}_2(\text{l}) + 3\text{H}_2\text{O}(\text{l})$	1.491	(67)
$\text{Ce}^{++++} + e = \text{Ce}^{+++}$	1.55	(5)
$\text{MnO}_4^- + 4\text{H}^+ + 3e = \text{MnO}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l})$	1.586	(6)
$\text{PbO}_2(\text{s}) + 4\text{H}^+ + \text{SO}_4^{--} + 2e = \text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l})$	1.6797	(38, 78)
$\text{Co}^{+++} + e = \text{Co}^{++}$	1.817	(34, 40)

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(For a key to the periodicals see end of volume)

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## ELECTROMOTIVE FORCE OF CELLS INVOLVING THE OXIDATION AND REDUCTION OF ORGANIC COMPOUNDS

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In Table 1 is listed the electromotive force of reversible cells corresponding to the chemical reaction  $\text{A}(\text{dis.}) + \text{H}_2 \rightleftharpoons \text{AH}_2(\text{dis.})$ . The recorded emf is either the directly measured emf of cell 1 or is calculated from the emf's of cells 2 and 3, on the assumption that the liquid junction potentials cancel.

- (1)  $[\text{Pt}] \text{H}_2(1 \text{ atm.}) | \text{H}^+(\text{c}_\text{H}) | \text{H}^+(\text{c}_\text{H}), \text{A}(\text{c}_1), \text{AH}_2(\text{c}_1) | \text{Pt} +$   
 (2)  $[\text{Pt}] \text{H}_2(1 \text{ atm.}) | \text{H}^+(\text{c}_\text{H}) | \text{N KCl} | \text{HgCl} | \text{Hg} +$   
 (3)  $\text{Hg} | \text{HgCl} | \text{N KCl} | \text{H}^+(\text{c}_\text{H}), \text{A}(\text{c}_1), \text{AH}_2(\text{c}_1) | \text{Pt} +$

The compounds listed in Table 1 are such that in the acid solutions employed the dissociation of  $\text{AH}_2$  into  $\text{A}^-$  or  $\text{AH}^-$  is negligible. Three methods have been employed in order to measure the emf: (1) the two substances have been added in known amounts; (2) the quinhydrone ( $\text{A} \cdot \text{AH}_2$ ) has been introduced into the cell; (3) the oxidized form has been titrated with a reducing agent (usually titanous chloride) and the mid-point of the titration curve determined graphically ( $[\text{A}] = [\text{AH}_2]$ ). The

three methods are designated in the tables as M, Q, and T, respectively. In a few cases the solution has been saturated with both A and  $\text{AH}_2$ , or with one of these substances and the corresponding quinhydrone ( $\text{A} \cdot \text{AH}_2$ ). These results have been listed in Table 2; from them may be calculated the free energy change of the reaction,  $\text{A}(\text{solid}) + \text{H}_2 \rightleftharpoons \text{AH}_2(\text{solid})$ . The free energy change of the reaction  $\text{A}(\text{gas}) + \text{H}_2 \rightleftharpoons \text{AH}_2(\text{gas})$  has been calculated for all the chloroquinones and xyloquinone (13).

(1, 4, 37) should be consulted for the measurement of the emf of cells of type 4 in various buffer solutions and the changes in emf due to variations in activity of the quinone and hydroquinone caused by the presence of salts.

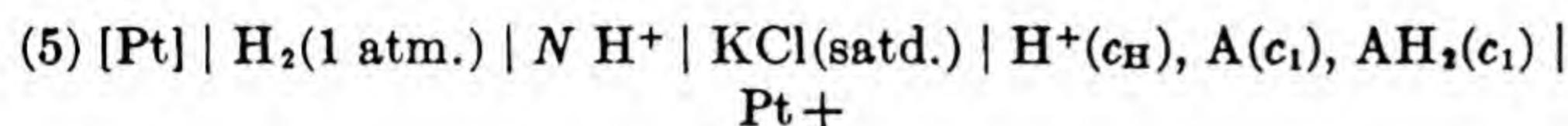
- (4)  $\text{Hg} | \text{HgCl} | \text{KCl}(\text{satd.}) | \text{H}^+(\text{c}_\text{H}), \text{quinhydrone} | \text{Pt} +$

For the application of the "quinhydrone electrode" to the determination of hydrogen ion activity in aqueous solution, see p. 330; and for solutions in absolute methyl alcohol, v. (26).



The relation of the emf's in aqueous and alcoholic solutions and slight changes due to the total acid concentration are dealt with in (16, 17, 18).

In Table 3 are summarized data concerning the emf of cells of type 5 in which the reaction for one reason or another does not correspond to the simple equation  $A + H_2 \rightleftharpoons AH_2$ , for the entire range of  $[H^+]$  investigated.



Such results as were obtained with varying values of  $[H^+] = c_H$  maintained by appropriate "buffer solutions," are best expressed in the form of equations involving  $[H^+]$  and certain experimentally determined constants. These constants and the equations are given in Table 3. The "normal oxidation-reduction potential" in a given  $[H^+]$  may be defined as the emf of cell 5. In calculating such potentials from the experimental results, liquid junction potentials have been ignored and the value of the hydrogen electrode in  $N/20$  acid potassium phthalate at  $30^\circ$  taken as 0.2386 volt.

For further details concerning the derivation of equations for oxidation-reduction potentials in solutions of varying  $[H^+]$ , (6, 7, 8) should be consulted. Preliminary data in regard to measurements of certain indophenols in one or two buffer solutions are given in (12), and a few preliminary measurements with certain sulfonated dyestuffs in  $pH = 0.76$  to  $12.7$  and in non-aqueous solvents are given in (20, 21). The potential of the reversible system hemoglobin-methemoglobin is given in (24), of quinone-imine-phenylenediamine in (23), of triphenylmethyl-triphenylmethyl sulfate in (25). For a study of merquinones of the phenylenediamine and benzidine series, see (10); for certain indamine dyes, see (35).

For a discussion of the errors inherent in the titration method, see (34); for a comparison of the titration method and method of mixtures, see (8, 11, 38).

For methods of estimating the "apparent reduction potential" and "apparent oxidation potential" of irreversible processes and other applications of reversible systems to the study of oxidation-reduction processes, see (14, 20, 21, 22, 23).

TABLE 1

Emf of cell:  $[Pt] | H_2(1 \text{ atm. dry}) | HCl(c_H) | HCl(c_H), A(c_1), AH_2(c_2) | Pt +$

Concn. of organic material, 0.001–0.005*N*. Quinones: the name of the oxidized compound, A, is listed; the reduced compound in every case was the corresponding hydroquinone. The probable error is 1–3 in the last place except in the values followed by a dagger, where the error may be as great as 5 millivolts.

A	<i>t</i> , °C	0.1 <i>N</i> HCl (aqueous), volt	Method	Lit.	0.5 <i>N</i> HCl, * 50 % C <sub>2</sub> H <sub>5</sub> OH, volt	Method	Lit.	0.5 <i>N</i> HCl, 95 % C <sub>2</sub> H <sub>5</sub> OH, volt	Method	Lit.
1, 4-Quinone.....	0	0.7172	Q	(3)	0.734	T	(16)		Q	(26)
	18	0.7044	Q	(1)					T	(16)
	25	0.6990	Q, M, T	(1, 33, 34)	0.713	T	(16)	0.711		
	37	0.690	Q	(3)						
	40	0.683	T	(16)	0.694	T	(16)			
1, 2-Quinone.....	25	0.787	T	(18)	0.784	T	(18)			
2-Methyl-1, 4-quinone (toluquinone).....	0	0.660	T	(16)	0.682	T	(16)			
	18	0.6507	Q	(1)						
	25	0.6454	Q	(1)	0.658	T	(16)	0.655	T	(16)
	40	0.631	T	(16)	0.640	T	(16)		T	(16)
2, 5-Dimethyl-1, 4-quinone ( <i>p</i> -xyloquinone).....	25	0.5900	T	(34)	0.601	T	(18)	0.600		
2, 3, 5-Trimethyl-1, 4-quinone (cumoquinone).....	25	0.527	T	(18)	0.529	T	(18)			
2-Methyl-5-isopropyl-1, 4-quinone (thymoquinone).....	25	0.5875	T	(34)	0.590	T	(18)			
2, 3, 5, 6-Tetramethyl-1, 4-quinone (duroquinone).....	25				0.466	T	(17)	0.467	T	(17)
Tetrahydro-1, 4-naphthoquinone.....	25	0.584	T	(15)	0.596	T	(15)	0.596	T	(17)
Monochloro-1, 4-quinone.....	25	0.7125	T	(34)	0.736	T	(17)	0.737	T	(18)
2, 3-Dichloro-1, 4-quinone.....	25	0.708	T	(17)				0.731†	T	(18)
2, 5-Dichloro-1, 4-quinone.....	25	0.720	T	(17)				0.733†	T	(17)
2, 6-Dichloro-1, 4-quinone.....	25	0.722	T	(17)				0.749	T	(17)
2, 3, 5-Trichloro-1, 4-quinone.....	25							0.732	T	(17)
2, 3, 5, 6-Tetrachloro-1, 4-quinone (chloranil).....	25							0.696	T	(17)
Monobromo-1, 4-quinone.....	25	0.7151	T	(34)	0.735	T	(18)			
3, 4, 5, 6-Tetrabromo-1, 2-quinone.....	25	0.823	T	(18)	0.873	T	(18)			
3, 4, 5, 6-Tetrachloro-1, 2-quinone.....	25	0.827	T	(18)	0.876	T	(18)			
2, 5-Dimethoxy-1, 4-quinone.....	25							0.477	T	(18)
2, 6-Dimethoxy-1, 4-quinone.....	25	0.5139	T	(34)	0.528	T	(18)	0.530	T	(18)
2, 5-Diethoxy-1, 4-quinone.....	25	0.465	T	(18)	0.474	T	(18)			
Hydroxy-1, 4-quinone.....	25	0.596	T	(18)	0.601	T	(18)			
2, 5-Dihydroxy-1, 4-quinone.....	25	0.443	T	(18)	0.434	T	(18)			
1, 2-Naphthoquinone.....	25	0.547	T	(16)	0.577	T	(16)	0.581	T	(16)
1, 4-Naphthoquinone.....	25	0.4698	T	(24)	0.483	T	(18)	0.495	T	(16)
2-Chloro-1, 4-naphthoquinone.....	25							0.510	T	(16)
2, 3-Dichloro-1, 4-naphthoquinone.....	25							0.500	T	(16)
2-Bromo-1, 4-naphthoquinone.....	25							0.508	T	(16)
1, 4-Naphthoquinone-2-sulfonic acid.....	24	0.534	T	(16)	0.559	T	(16)	0.554	T	(16)
1, 2-Naphthoquinone-4-sulfonic acid.....	25	0.628	T	(18)	0.636	T	(18)			
1, 2-Naphthoquinone-4, 6-disulfonic acid.....	25	0.660	T	(18)	0.653	T	(18)			
2-Hydroxy-1, 4-naphthoquinone.....	25				0.357	T	(18)			
8-Hydroxy-1, 4-naphthoquinone.....	25				0.453	T	(18)			
2-Hydroxy-3-chloro-1, 4-naphthoquinone.....	25				0.352	T	(18)	0.350	T	(18)
2, 3-Diphenoxy-1, 4-naphthoquinone.....	25							0.457		
Naphthopurpurin (2, 4, 8-trihydroxy-1, 4-naphthoquinone).....	25				0.243*	T	(28)			
Naphthazarin (5, 8-dihydroxy-1, 4-naphthoquinone).....	25				0.361*	T	(28)			
2, 6-Dihydroxy-1, 4-naphthoquinone.....	25				0.303*	T	(28)			
2-Allyl-3-hydroxy-1, 4-naphthoquinone.....	25				0.299*	T	(28)			
2-( $\alpha$ -Methylallyl)-3-hydroxy-1, 4-naphthoquinone.....	25				0.287*	T	(28)			
2-( $\gamma$ -Methylallyl)-3-hydroxy-1, 4-naphthoquinone.....	25				0.295*	T	(28)			



TABLE 1.—(Continued)

A	t, °C	0.1N HCl (aqueous), volt	Method	Lit.	0.5N HCl,* 50 % C <sub>2</sub> H <sub>5</sub> OH, volt	Method	Lit.	0.5N HCl, 95 % C <sub>2</sub> H <sub>5</sub> OH, volt	Method	Lit.
Lapachol.....	25				0.287*	T	(28)			
Hydrolapachol.....	25				0.285*	T	(28)			
Chlorohydrolapachol.....	25				0.297*	T	(28)			
2-(β-Chloropropyl)-3-hydroxy-1, 4-naphthoquinone.....	25				0.304*	T	(28)			
Dibromohydrolapachol.....	25				0.291*†	T	(28)			
Hydroxyhydrolapachol.....	25				0.295*†	T	(28)			
Lomatol.....	25				0.294*	T	(28)			
Hydroxyislapachol.....	25				0.310*	T	(28)			
2-(β-Hydroxypropyl)-3-hydroxy-1, 4-naphthoquinone.....	25				0.308*	T	(28)			
Iso-β-lapachol.....	25				0.282*	T	(28)			
2-Benzyl-3-hydroxy-1, 4-naphthoquinone.....	25				0.296*	T	(28)			
1-Methyl-5, 6-benzo-3, 4-coumaranequinone.....	25				0.406*	T	(28)			
1, 2-Dimethyl-5, 6-benzo-3, 4-coumaranequinone.....	25				0.407*	T	(28)			
2-Methyl-7, 8-benzo-5, 6-chromanequinone.....	25				0.399*	T	(28)			
2-Phenyl-7, 8-benzo-5, 6-chromanequinone.....	25				0.413*	T	(28)			
β-Lapachone.....	25				0.403*	T	(28)			
Bromo-β-lapachone.....	25				0.427*	T	(28)			
Hydroxy-β-lapachone.....	25				0.411*	T	(28)			
Isopropylfurane-β-naphthoquinone.....	25				0.460*	T	(28)			
1-Methyl-4, 5-benzo-3, 6-coumaranequinone.....	25				0.375*	T	(28)			
2-Methyl-6, 7-benzo-5, 8-chromanequinone.....	25				0.307*	T	(28)			
α-Lapachone.....	25				0.304*	T	(28)			
Hydroxy-α-lapachone.....	25				0.320*	T	(28)			
Isopropylfurane-α-naphthoquinone.....	25				0.283*	T	(28)			
Isonaphthazarin (2, 3-dihydroxy-1, 4-naphthoquinone).....	25				0.282*	T	(28)			
Isonaphthazarin monomethyl ether.....	25				0.329*	T	(28)			
Isonaphthazarin dimethyl ether.....	25				0.387*	T	(28)			
1-Methyl-5, 6-(β, β-naphtho)-3, 4-coumaranequinone.....	25				0.305*	T	(28)			
9, 10-Phenanthraquinone.....	25	0.442	T	(28)	0.458*	T	(28)	0.472	T	(18)
1-Methyl-7-isopropyl-9, 10-phenanthraquinone (retenequinone).....	25							0.409	T	(18)
1, 2-Phenanthraquinone.....	25				0.651*	T	(30)			
3, 4-Phenanthraquinone.....	25				0.614*	T	(30)			
3, 4-Phenanthraquinone-1-sulfonic acid.....	25	0.664	T	(30)						
2-Hydroxy-1, 4-phenanthraquinone.....	25				0.410*	T	(30)			
3-Hydroxy-1, 4-phenanthraquinone.....	25				0.396*	T	(30)			
2-Methoxy-1, 4-phenanthraquinone.....	25				0.418*	T	(30)			
3-Methoxy-1, 4-phenanthraquinone.....	25				0.409*	T	(30)			
9, 10-Phenanthraquinone-3-sulfonic acid.....	25	0.472	T	(30)						
1, 2-Anthraquinone.....	25							0.493	T	(18)
1, 4-Anthraquinone.....	25				0.401*	T	(29)			
9, 10-Anthraquinone.....	25							0.157	T	(18)
Anthraquinone acids, v. Table 3										
2-Methyl-9, 10-anthraquinone.....	25							0.153	T	(18)
2-Chloromethyl-9, 10-anthraquinone.....	25							0.184†	T	(18)
1-Chloro-9, 10-anthraquinone.....	25							0.176	T	(18)
2-Chloro-9, 10-anthraquinone.....	25							0.203	T	(18)
2, 7-Dichloro-9, 10-anthraquinone.....	25							0.226†	T	(18)
9, 10-Anthraquinone-2-carboxylic acid.....	25							0.214	T	(18)
Methyl 9, 10-anthraquinone-2-carboxylate.....	25							0.225	T	(18)
Ethyl 9, 10-anthraquinone-2-carboxylate.....	25							0.224	T	(18)
2-Hydroxy-1, 4-anthraquinone.....	25				0.275*	T	(29)			
6, 7-Indazolequinone-4-sulfonic acid.....	25	0.620	T	(27)						
2-Phenylbenzotriazole-4, 5-quinone-7-sulfonic acid.....	25	0.644	T	(31)						
2-Phenyl-α, β-naphthotriazole-4, 5-quinone.....	25				0.470*	T	(31)			
3-Phenyl-α, β-naphthotriazole-4, 5-quinone.....	25				0.513*	T	(31)			
α, β-Naphthimidazole-4, 5-quinone.....	25				0.528*	T	(31)			
2-Methyl-3-phenyl-β, β-naphthimidazole-4, 9-quinone.....	25				0.320*	T	(31)			
1-(p-Tolyl)-β, β-naphthotriazole-4, 9-quinone.....	25				0.244*†	T	(31)			
Thionaphthenequinone.....	25	0.264	T	(31)						
Thiophanthraquinone.....	25				0.250*	T	(31)			
α, β-Naphthotriazole-4, 5-quinone.....	25	0.465	T	(31)						
α-Naphthoquinolinequinone.....	25	0.554	T	(31)						

A	AH <sub>2</sub>	t, °C	0.1N HCl (aqueous)	Method	Lit.
Nitrosobenzene.....	Phenylhydroxylamine	25	0.60s†	T, M	(20)
1-Nitroso-2-naphthol.....	1-Hydroxylamino-2-naphthol	25	0.52s†	T	(20)
3, 3'-Diamino-4, 4'-dimethylazobenzene (asotoluidine).....	3, 3'-Diamino-4, 4'-dimethylhydrazobenzene	18	0.375	M	(2)
		25	0.367	M	(2)
3, 3'-Diaminoazobenzene.....	3, 3'-Diaminohydrazobenzene	18	0.414	M	(2)
		37	0.402	M	(2)
Potassium azobenzene-4, 4'-disulfonate.....	Potassium hydrazobenzene-4, 4'-disulfonate	25	0.424	M	(22)

For the potentials of sulfonated dyestuffs, methylene blue and other dyes, see Table 3.

\* Or 0.1N HCl and 0.2N LiCl



TABLE 2

Emf of cell: [Pt] | H<sub>2</sub>(1 atm. dry) | H<sup>+</sup>(c<sub>H</sub>) | H<sup>+</sup>(c<sub>H</sub>), A(satd.), B(satd.) | [Pt] +

Accuracy: ±1 in the third place, resp. 1-3 in the fourth place

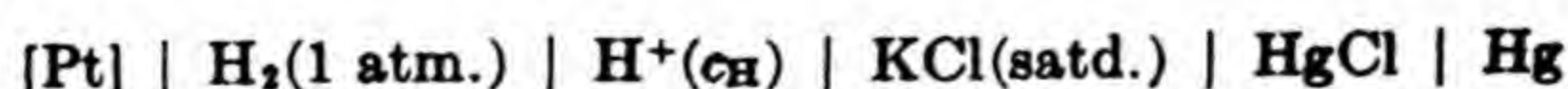
Half-cell was saturated with	Solvent	°C	Volt	Lit.
1, 4-Quinone.....	0.1N aq. HCl	0	0.770	(17)
Quinhydrone of 1, 4-quinone.....		5	0.7665	(36)
		10	0.7620	(36)
		18	0.7562	(4)
		25	0.749	(17)
1, 4-Hydroquinone.....	0.1N aq. HCl	0	0.627	(17)
Quinhydrone of 1, 4-quinone.....		12	0.6215	(36)
		18	0.6177	(4)
		22	0.6150	(36)
		25	0.6123	(17, 33)
2-Methyl-1, 4-quinone.....	0.1N aq. HCl	32	0.6085	(36)
Quinhydrone of 2-methyl-1, 4-quinone.....		0	0.677	(17)
2-Methyl-1, 4-hydroquinone.....	0.1N aq. HCl	25	0.661	(17)
Quinhydrone of 2-methyl-1, 4-quinone.....		0	0.610	(17)
2, 5-Dimethyl-1, 4-quinone ( <i>p</i> -xyloquinone).....	0.1N aq. HCl	25	0.584	(17)
2, 5-Dimethyl-1, 4-hydroquinone ( <i>p</i> -xylohydroquinone).....		0	0.600	(17)
2-Methyl-5-isopropyl-1, 4-quinone (thymoquinone).....	0.1N aq. HCl	25	0.582	(17)
Quinhydrone of 2-methyl-5-isopropyl-1, 4-quinone.....		0	0.605	(17)
2-Methyl-5-isopropyl-1, 4-hydroquinone (thymohydroquinone).....	0.1N aq. HCl	25	0.593	(17)
Quinhydrone of 2-methyl-5-isopropyl-1, 4-quinone.....		0	0.592	(17)
2, 3, 5, 6-Tetramethyl-1, 4-quinone (duroquinone).....	50 % C <sub>2</sub> H <sub>5</sub> OH in 1N HCl	25	0.566	(17)
2, 3, 5, 6-Tetramethyl-1, 4-hydroquinone.....		0	0.499	(17)
Monochloro-1, 4-quinone.....	0.1N HCl satd. with NaCl	25	0.481	(17)
Quinhydrone of monochloro-1, 4-quinone.....		0	0.740	(17)
Monochloro-1, 4-hydroquinone.....	0.1N HCl satd. with NaCl	25	0.722	(17)
Quinhydrone of monochloro-1, 4-quinone.....		0	0.651	(17)
2, 6-Dichloro-1, 4-quinone.....	0.1N HCl satd. with NaCl	25	0.634	(17)
Quinhydrone of 2, 6-dichloro-1, 4-quinone.....		0	0.743	(17)
2, 6-Dichloro-1, 2,4-hydroquinone.....	0.1N HCl satd. with NaCl	25	0.726	(17)
Quinhydrone of 4 6-dichloro-1, 4-hydroquinone.....		0	0.690	(17)
2, 3-Dichloro-1, -quinone.....	0.1N HCl satd. with NaCl	25	0.669	(17)
2, 3-Dichloro-1, 4-hydroquinone.....		0	0.692	(17)
2, 5-Dichloro-1, 4-quinone.....	0.1N aq. HCl	25	0.675	(17)
2, 5-Dichloro-1, 4-hydroquinone.....		0	0.710	(17)
2, 3, 5-Trichloro-1, 4-quinone.....	0.1N aq. HCl	25	0.689	(17)
Quinhydrone of 2, 3, 5-trichloro-1, 4-quinone.....		25	0.681	(17)
2, 3, 5-Trichloro-1, 4-hydroquinone.....	0.1N aq. HCl	25	0.661	(17)
Quinhydrone of 2, 3, 5-trichloro-1, 4-quinone.....		0	0.690	(17)
2, 3, 5-Trichloro-1, 4-quinone.....	0.1N aq. HCl	25	0.670	(17)
2, 3, 5-Trichloro-1, 4-hydroquinone.....		0	0.683	(17)
2, 3, 5, 6-Tetrachloro-1, 4-quinone.....	0.1N aq. HCl	25	0.664	(17)
2, 3, 5, 6-Tetrachloro-1, 4-hydroquinone.....		18	0.3699	(5)
Alloxantin.....	0.1N H <sub>2</sub> SO <sub>4</sub>	25	0.3664	(5)
N, N-Tetramethylalloxantin.....	0.1N H <sub>2</sub> SO <sub>4</sub>	18	0.3657	(5)

TABLE 3

Emf of the cell: [Pt] | H<sub>2</sub>(1 atm.) | N H<sup>+</sup> | KCl(satd.) | H<sup>+</sup>(c<sub>H</sub>), A(c<sub>1</sub>), AH<sub>2</sub>(c<sub>2</sub>) | Pt +

As computed from measurements against the calomel half cell

The variation in emf as a function of [H<sup>+</sup>] = c<sub>H</sub> is given by one of several types of equations listed below. The value of [H<sup>+</sup>] was determined from the emf of the cell



Liquid junction potentials were neglected in determining both the value of [H<sup>+</sup>] and that of the oxidation reduction cell involving the "normal hydrogen electrode." The ultimate working standard was the hydrogen electrode in N/20 potassium acid phthalate to which the value 0.2386 volt at 30° referred to the "normal hydrogen electrode" was assigned. The type of equation and the experimentally determined constants are listed in the tables as well as the range of [H<sup>+</sup>] in which the measurements were made. The concentration of organic material was 0.001-0.005 molar. The results are significant within 1 or 2 mv except with the anthraquinone derivatives where the error may be 3-5 mv.



TABLE 3.—(Continued)

$$(A) E_0 - \frac{RT}{2F} \log \frac{c_2}{c_1} + \frac{RT}{2F} \log [K_1[H^+] + [H^+]^2]$$

$$(B) E_0 - \frac{RT}{2F} \log \frac{c_2}{c_1} + \frac{RT}{2F} \log [K_1K_2 + K_1[H^+] + [H^+]^2]$$

$$(C) E_0 - \frac{RT}{2F} \log \frac{c_2}{c_1} + \frac{RT}{2F} \log [K_rK_2[H^+] + K_r[H^+]^2 + [H^+]^3] - \frac{RT}{2F} \log (K_0 + [H^+])$$

$$(D) E_0 - \frac{RT}{2F} \log \frac{c_2}{c_1} - \frac{RT}{2F} \log \left[ \frac{K_{obs}[H^+] + K_w}{K_{r2}K_{r3}[H^+]^2 + K_{r3}[H^+]^3 + [H^+]^4} \right]$$

where  $E_0$  is given in volt,  $[H^+]$  determined as stated above,  $K_1$  and  $K_2$  the acid dissociation constants of phenolic groups formed by the reduction, and  $K_r$  and  $K_0$  the acid dissociation constants in the reduced and oxidized compounds, respectively, of an acidic group common to both.

Oxidized compound A	Reduced compound AH <sub>2</sub>	Type of equation	°C	pH range investigated	Constants					Method	Lit.
					$E_0$ , volt	$K_1$	$K_2$	$K_0$	$K_r$		
Indigo-5-sulfonic acid.....	Leucoindigo-5-sulfonic acid	A	30	1.1-12.6	0.262	$1.6 \times 10^{-8}$				M	(38)
Indigo-5, 5'-disulfonic acid...	Leucoindigo-5, 5'-disulfonic acid	A	30	1.1-12.6	0.291	$4.9 \times 10^{-8}$				M	(38)
Indigo-5, 5', 7-trisulfonic acid	Leucoindigo-5, 5', 7-trisulfonic acid	A	30	1.1-12.6	0.332	$7.7 \times 10^{-8}$				M	(38)
Indigo-5, 5', 7, 7'-tetrasulfonic acid.	Leucoindigo-5, 5', 7, 7'-tetrasulfonic acid	A	30	1.1-12.6	0.365	$11.2 \times 10^{-8}$				M	(38)
1-Naphthol-4-indophenol-2-sulfonic acid	Leuco-1-naphtholindophenol-2-sulfonic acid	C	30	1.1-12.6	0.544		$2.0 \times 10^{-11}$	$2.1 \times 10^{-9}$	$8.0 \times 10^{-10}$	M, T	(8)
Phenol-4-indophenol.....	Leucophenolindophenol	C	30	6.2-12.3	0.649		$2.3 \times 10^{-11}$	$8.0 \times 10^{-9}$	$3.6 \times 10^{-10}$	M, T	(11)
<i>o</i> -Cresol-4-indophenol.....	Leuco- <i>o</i> -cresolindophenol	C	30	6.3-12.3	0.616		$1.3 \times 10^{-11}$	$4.2 \times 10^{-9}$	$3.0 \times 10^{-10}$	M, T	(11)
<i>m</i> -Cresol-4-indophenol.....	Leuco- <i>m</i> -cresolindophenol	C	30	6.3-12.3	0.632		$2.2 \times 10^{-11}$	$2.8 \times 10^{-9}$	$2.7 \times 10^{-10}$	M, T	(11)
Thymol-4-indophenol.....	Leucothymolindophenol	C	30	5.7-12.3	0.592		$1.5 \times 10^{-11}$	$1.6 \times 10^{-9}$	$1.4 \times 10^{-10}$	M, T	(11)
Carvacrol-4-indophenol.....	Leucocarcacrolindophenol	C	30	5.7-12.3	0.593		$1.8 \times 10^{-11}$	$1.4 \times 10^{-9}$	$1.4 \times 10^{-10}$	M, T	(11)
<i>o</i> -Bromophenol-4-indophenol.	Leuco- <i>o</i> -bromophenolindophenol	C	30	5.8-11.7	0.659		$5.8 \times 10^{-11}$	$7.8 \times 10^{-9}$	$3.0 \times 10^{-9}$	M, T	(11)
<i>m</i> -Bromophenol-4-indophenol.	Leuco- <i>m</i> -bromophenolindophenol	C	30	5.2-11.7	0.670		$5.0 \times 10^{-11}$	$1.5 \times 10^{-8}$	$1.1 \times 10^{-9}$	M, T	(11)
<i>o</i> -Chlorophenol-4-indophenol.	Leuco- <i>o</i> -chlorophenolindophenol	C	30	4.0-12.3	0.663		$5.0 \times 10^{-11}$	$1.0 \times 10^{-7}$	$3.6 \times 10^{-9}$	M, T	(11)
<i>o</i> -Cresolindo-2, 6-dichlorophenol.	Leuco- <i>o</i> -cresolindo-2, 6-dichlorophenol	C	30	5.7-11.4	0.639		$3.7 \times 10^{-11}$	$3.2 \times 10^{-8}$	$8 \times 10^{-8}$	M, T	(32)
Phenolindo-2, 6-dichlorophenol.	Leucophenolindo-2, 6-dichlorophenol	C	30	6.3-11.4	0.668		$7.4 \times 10^{-11}$	$2 \times 10^{-8}$	$1 \times 10^{-7}$	M, T	(32)
<i>o</i> -Chlorophenolindo-2, 6-dichlorophenol.	Leuco- <i>o</i> -chlorophenolindo-2, 6-dichlorophenol	C	30	5.7-11.4	0.668		$1.8 \times 10^{-9}$	$1.6 \times 10^{-8}$	$9 \times 10^{-8}$	M, T	(32)
1-Naphthol-2-sulfonate-indo-2, 6-dichlorophenol.....	Leuco-compound	C	30	5.0-11.4	0.563		$4.787 \times 10^{-10}$	$7.245 \times 10^{-7}$	$3.549 \times 10^{-8}$	M, T	(32)
<i>m</i> -Cresol-2-indophenol.....	Leuco- <i>m</i> -cresol-2-indophenol	C	30	5.7-12.3	0.647		$2.0 \times 10^{-11}$	$4.2 \times 10^{-9}$	$4.5 \times 10^{-10}$	M, T	(12)
Phenol-4-indo-2', 6'-dibromophenol.	Leucophenol-4-indo-2', 6'-dibromophenol	C	30	7.0-12.3	0.668		$8.9 \times 10^{-11}$	$2 \times 10^{-8}$	$1 \times 10^{-7}$	M, T	(12)
9, 10-Anthraquinone-1-sulfonic acid.	9, 10-Anthrahydroquinone-1-sulfonic acid	A	0 25 40	3 and 4.3 1.2-13.7 3 and 4.3	0.209 0.195 0.186	(?) $0.4 \times 10^{-8}$ (?)				T	(19)
9, 10-Anthraquinone-1, 5-disulfonic acid.	9, 10-Anthrahydroquinone-1, 5-disulfonic acid	A	0 25 40	3, 4 and 6 1.2-13.7 3, 4 and 6	0.251 0.239 0.230	(?) $3 \times 10^{-12}$ (?)				T T T	(16) (19) (16)
9, 10-Anthraquinone-1, 8-disulfonic acid.	9, 10-Anthrahydroquinone-1, 8-disulfonic acid	A	25	1.2-13.7	0.206	$0.7 \times 10^{-8}$				T	(19)
9, 10-Anthraquinone-2-sulfonic acid.	9, 10-Anthrahydroquinone-2-sulfonic acid	B	0 25 40	3, 6 and 7 1.2-13.7 3, 6 and 7	0.198 0.187 0.172	(?) $1 \times 10^{-8}$ (?)	$5 \times 10^{-12}$			T T T	(16) (19) (16)
9, 10-Anthraquinone-2, 6-disulfonic acid.	9, 10-Anthrahydroquinone-2, 6-disulfonic acid	B	0 25 40	3 and 7 1.2-13.7 3 and 7	0.240 0.228 0.210	(?) $0.8 \times 10^{-8}$ (?)	$3 \times 10^{-11}$			T T T	(16) (19) (16)
9, 10-Anthraquinone-2, 7-disulfonic acid.	9, 10-Anthrahydroquinone-2, 7-disulfonic acid	B	0 25 40	3 and 7 1.2-13.7 3 and 7	0.243 0.229 0.215	(?) $2 \times 10^{-8}$ (?)	$3 \times 10^{-11}$			T T T	(16) (19) (16)
1, 2-Anthraquinone-4-sulfonic acid.	1, 2-Anthrahydroquinone-4-sulfonic acid		25	0.76	0.530					T	(29)

Compounds with which equation D must be employed.

		Type of equation	°C	pH range investigated	$E'_0$	$K_{r1}$	$K_{r2}$	$K_{obs.}$	$K_r$	Method	Lit.
Methylene blue.....	Methylene white	D	30	1-12	0.532	$1.4 \times 10^{-8}$	$3 \times 10^{-8}$	negligible		T	(9)
Lauth's violet.....	Leuco-compound	D	30	1-12.6	0.536	$5 \times 10^{-8}$	$4.2 \times 10^{-8}$	$1.88 \times 10^{-8}$		T	(9)

$$* E'_0 = E_0 - \frac{RT}{2F} \log \frac{c_2}{c_1}$$

NOTE.—Concentrations 0.0001 to 0.00006N.



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## LIQUID JUNCTION POTENTIALS

DUNCAN A. MACINNES

The emf ( $E_L$ ), of liquid junctions, ||, in galvanic cells may be obtained for four types of junction: (1)  $M_1A(C_1)||M_2A(C_1)$  or  $MA_1(C_1)||MA_2(C_1)$ ; (2)  $M_1A(C)||M_2A(Cx) + M_1A[C(1-x)]$ ; (3)  $MA(C_1)||MA(C_2)$ ; and (4) saturated  $KCl||MA$ .  $M$  and  $A$  represent univalent cations and anions respectively;  $C_1$  and  $C_2$ , concentrations. For type (1),  $E_L = \frac{RT}{F} \log \frac{\Lambda_1}{\Lambda_2}$  (approximately), where  $\Lambda$  is the equivalent conductance at the (single) concentration involved (13, 15). Type (2) may be computed from the relation:

$E_L = RT/F \cdot \log_e [(1 - t_2) - x(t_1 - t_2)] / (1 - t_1)$ , ( $t_1$  and  $t_2$  are the transference numbers of the ion constituents  $M_1$  and  $M_2$ , and  $x$  is a factor less than unity) (23). For type (3)  $E_L = \frac{(1 - 2t)RT}{F} \log \frac{a_1}{a_2}$ , if the ions have the same activities,  $a$ , at each concentration ( $t$  is the transference number) (14). Type (4) junctions can be regarded as constant, for most purposes, for concentration changes of  $MA$  up to 0.1N (3, 8, 17).

Cells		$t$ , °C	Emf, millivolt	Literature and remarks
+Au	$K_4Fe(CN)_6$ KCl(0.2N)    KAc(0.2N) $K_4Fe(CN)_6$   Au.....	25	6.9	(13)
+Au	$K_3Fe(CN)_6$ KCl(0.1N)    KAc(0.1N) $K_4Fe(CN)_6$   Au.....	25	6.9	Equal small amounts of ferro- and ferri-cyanides in both half cells. Potentials closely that of liquid junction.
-Au	$K_4Fe(CN)_6$ KCl(0.2N)    KOH(0.2N) $K_4Fe(CN)_6$   Au.....	25	16.1	
-Au	$K_3Fe(CN)_6$ KCl(0.1N)    KOH(0.1N) $K_4Fe(CN)_6$   Au.....	25	15.7	
+Au	$K_4Fe(CN)_6$ KCl(0.2N)    KBr(0.2N) $K_4Fe(CN)_6$   Au.....	25	0.4	
-Au	$K_4Fe(CN)_6$ NaCl(0.2N)    NaOH(0.1N) $K_4Fe(CN)_6$   Au.....	25	18.1	
-Ag	AgCl, HCl(0.1N)    KCl(0.1N) AgCl   Ag.....	25	27.8	(12)
-Ag	AgCl, HCl(0.01N)    KCl(0.01N) AgCl   Ag.....	25	27.2	
Ag   AgCl, $M_1Cl$ (0.1N)    $M_2Cl$ (0.1N), AgCl   Ag.....		25	$E_1 - E_2$	(15)
Values of $E$ , LiCl, 35.65; KCl, 26.78; HCl, 0.00; NaCl, 33.08; $NH_4Cl$ , 28.78, millivolt.		25	$E_1 - E_2$	Flowing junctions(11). Potential in millivolts obtained by subtracting figure given for $M_2Cl$ from value for $M_1Cl$ , the resulting algebraic sign is the sign of the potential of the left-hand electrode. If the activities of the chloride ion are the same, at the concentration given, the potential thus computed is that of the liquid junction.
Ag   AgCl, $M_1Cl$ (0.01N)    $M_2Cl$ (0.01N), AgCl   Ag.....		25	$E_1 - E_2$	
Values of $E$ , LiCl, 33.82; KCl, 25.62; HCl, 0.00; NaCl, 31.19; $NH_4Cl$ , 26.93; CsCl, 26.02, millivolt.				
-Ag	AgCl, HCl(0.1N)    NaCl(0.02346N) HCl(0.07654N), AgCl   Ag.....	25	4.75	(24)
-Ag	AgCl, HCl(0.1N)    NaCl(0.05050N) HCl(0.04950N), AgCl   Ag.....	25	11.85	Type 2 (see above). Flowing junctions. Measured potentials close to liquid junction potentials.
-Ag	AgCl, HCl(0.1N)    NaCl(0.06142N) HCl(0.03858N), AgCl   Ag.....	25	15.12	
-Ag	AgCl, HCl(0.1N)    NaCl(0.07518N) HCl(0.02482N), AgCl   Ag.....	25	20.17	
-Ag	AgCl, HCl(0.1N)    NaCl(0.08931N) HCl(0.01069N), AgCl   Ag.....	25	26.80	
-Ag	AgCl, HCl(0.1N)    NaCl(0.09400N) HCl(0.00600N), AgCl   Ag.....	25	29.41	

Potentials at junctions of aqueous solutions of electrolytes with solutions in immiscible solvents, see (1, 2, 18, 19, 20, 21, 22).  
Potentials at membranes, see (5, 6, 7).



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## OVERVOLTAGE

MAX KNOBEL

Overvoltage is the potential necessary to discharge the ion in question in excess of that necessary for reversible discharge, the reversible and irreversible electrodes being under the same condition of temperature, pressure, electrolyte, etc.

The actual magnitude of any overvoltage value cannot be specified precisely because of uncontrollable variability. The usual reproducibility is not better than 0.05 volt.

All values given are determined by the "direct" method, that is, while the polarizing current is flowing. For references on the comparative value of commutator and direct method, see (2, 3, 5, 9, 10, 14).

## EFFECT OF CURRENT DENSITY ON OVERVOLTAGE (7)

*Smooth Electrodes unless Otherwise Designated.*—Electrolyte for hydrogen overvoltages is 2N H<sub>2</sub>SO<sub>4</sub>; for halogen overvoltages, a saturated solution of the sodium or potassium halide with the halogen; for oxygen overvoltages, 1N KOH. The hydrogen overvoltages are most reliable and by careful duplication of conditions are reproducible to 0.1 volt or better. The halogen overvoltages are the least reliable due to coatings on the electrode.

For other references on the effect of current density, see the above article. It is impracticable to attempt to average the results of different investigators on account of the sensitivity of overvoltage to many conditions of measurement.

## HYDROGEN OVERVOLTAGES AT 25°C

Milliamp per cm <sup>2</sup>	Overvoltage in volt						
	Au	Cd	Cu	Platinized Pt	Smooth Pt	Al	Graphite
0		0.466		0.000			0.0022
0.1	0.122	0.651	0.351	0.0034		0.499	0.3166
1	0.241	0.981	0.479	0.0154	0.024	0.565	0.5995
2				0.0208	0.034	0.625	0.6520
5	0.332	1.086	0.548	0.0272	0.051	0.745	0.7250
10	0.390	1.134	0.584	0.0300	0.068	0.826	0.7788
50	0.507	1.211		0.0376	0.186	0.968	0.9032
100	0.588	1.216	0.801	0.0405	0.288	0.996	0.9774
200	0.668	1.228	0.988	0.0420	0.355	1.176	1.0794
500	0.770	1.246	1.186	0.0448	0.573	1.237	1.1710
1000	0.798	1.254	1.254	0.0483	0.676	1.286	1.2200
1500	0.807	1.257	1.269	0.0495	0.768	1.292	1.2208

Milliamp per cm <sup>2</sup>	Overvoltage in volt						
	Ag	Sn	Fe electrode	Brass	Monel metal	Dur-iron	
0		0.2411	0.2026				0.1680
0.1	0.2981	0.3995	0.2183	0.3832	0.1911		0.1710
1	0.4751	0.8561	0.4036	0.4967	0.2754		0.1970
2	0.5787	0.9469	0.4474	0.5346	0.3022		0.2136
5	0.6922	1.0258	0.5024	0.5960	0.3387		0.2443

## HYDROGEN OVERVOLTAGES.—(Continued)

Milliamp per cm <sup>2</sup>	Overvoltage in volt					
	Ag	Sn	Fe electrode	Brass	Monel metal	Dur iron
10	0.7618	1.0767	0.5571	0.6459	0.3832	0.2856
50	0.8300	1.1851	0.7000	0.8011	0.5345	0.5096
100	0.8749	1.2230	0.8184	0.9104	0.6244	0.6129
200	0.9379	1.2342	0.9854	1.1088	0.7108	0.7240
500	1.0300	1.2380	1.2561	1.2318	0.8619	0.8591
1000	1.0890	1.2306	1.2915	1.2544	1.0716	1.0205
1500	1.0841	1.2286	1.2908	1.2491	1.2095	1.1400

Milliamp per cm <sup>2</sup>	Overvoltage in volt				
	Zn	Carbon	Bi	Ni	Pb
1	0.716		0.78	0.563	0.52
2	0.726			0.633	
5	0.726	0.64	0.98	0.705	1.060
10	0.746	0.70	1.05	0.747	1.090
50	0.926	0.82	1.15	0.890	1.168
100	1.064	0.89	1.14	1.048	1.179
300	1.168	1.04	1.20	1.130	1.217
500	1.201	1.10	1.21	1.208	1.235
1000	1.229	1.17	1.23	1.241	1.262
1500	1.243	1.23	1.29	1.254	1.290

Milliamp per cm <sup>2</sup>	Over-voltage Hg	Milli-amp per cm <sup>2</sup>	Over-voltage Te	Milli-amp per cm <sup>2</sup>	Over-voltage Pd
0.00	0.2805	0.416	0.0504	0.227	0.0546
0.0769	0.5562	0.832	0.3505	1.135	0.1392
0.769	0.8488	1.667	0.4162	2.27	0.1820
1.54	0.9295	4.16	0.4405	4.54	0.2349
3.87	1.0060	8.32	0.4300	11.35	0.3165
7.69	1.0361	41.6	0.4705	22.7	0.4034
38.7	1.0634	83.2	0.4733	113.5	0.7205
76.9	1.0665	166.7	0.4986	227	0.8607
154	1.0751	416	0.5370	454	0.9521
387	1.1053	832	0.5940	1135	1.0513
769	1.108	1250	0.6590	2270	1.1168
1153	1.126			3400	1.1570

## CHLORINE OVERVOLTAGES AT 25°C

Platinized Pt		Smooth Pt		Graphite	
Milliamp per cm <sup>2</sup>	Over-voltage	Milliamp per cm <sup>2</sup>	Over-voltage	Milliamp per cm <sup>2</sup>	Over-voltage
1.1	0.0060	1.1	0.008	40	0.186
5.7	0.0140	5.7	0.0199	70	0.193
14.5	0.0180	11.4	0.0299	100	0.251
21.7	0.0190	22.8	0.0378	200	0.298



CHLORINE OVERVOLTAGES —(Continued)

Platinized Pt		Smooth Pt		Graphite	
Milliamp per cm <sup>2</sup>	Over-voltage	Milliamp per cm <sup>2</sup>	Over-voltage	Milliamp per cm <sup>2</sup>	Over-voltage
38.8	0.0210	43.0	0.0457	500	0.417
60	0.024	100	0.0540	740	0.466
100	0.026	200	0.0870	980	0.489
200	0.035	500	0.161	1131	0.535
520	0.050	750	0.212		
1340	0.089	1000	0.236		
1490	0.103	1350	0.263		

BROMINE OVERVOLTAGES AT 25°C

Platinized platinum		Smooth platinum		Graphite	
Milliamp per cm <sup>2</sup>	Over-voltage	Milliamp per cm <sup>2</sup>	Over-voltage	Milliamp per cm <sup>2</sup>	Over-voltage
10	0.002	20	0.002	10	0.002
30	0.005	30	0.004	30	0.008
50	0.007	50	0.006	50	0.016
100	0.012	230	0.033	100	0.027
200	0.025	300	0.057	200	0.054
300	0.041	360	0.113	300	0.081
420	0.056	400	0.156	390	0.108
500	0.069	420	0.164	550	0.163
590	0.082	440	0.178	740	0.218
760	0.130	520	0.266	840	0.253
940	0.202	720	0.379	990	0.329
				1110	0.356
				1210	0.400

IODINE OVERVOLTAGES AT 25°C

Platinized platinum		Smooth platinum		Graphite	
Milliamp per cm <sup>2</sup>	Over-voltage	Milliamp per cm <sup>2</sup>	Over-voltage	Milliamp per cm <sup>2</sup>	Over-voltage
10	0.006	12.3	0.0039	1.2	0.002
20	0.012	23	0.0070	5.7	0.007
40	0.022	50	0.0127	11.7	0.0139
110	0.032	90	0.0216	19.7	0.0239
220	0.050	130	0.0353	34.8	0.0348
400	0.070	200	0.0510	50	0.0538
710	0.118	310	0.0744	100	0.0974
810	0.130	520	0.120	200	0.175
1000	0.196	690	0.150	400	0.315
1300	0.216	1030	0.220	590	0.451
1460	0.266	1160	0.245	840	0.645
		1330	0.277		
		1500	0.292		

OXYGEN OVERVOLTAGES AT 25°C

Milliamp per cm <sup>2</sup>	Overvoltage in volt			
	Soft graphite	Au	Cu	Ag
1	0.525	0.673	0.422	0.580
5	0.705	0.927	0.546	0.674
10	0.896	0.963	0.580	0.729
20	0.963	0.996	0.605	0.813
50		1.064	0.637	0.912
100	1.091	1.244	0.660	0.984
200	1.142		0.687	1.038
500	1.186	1.527	0.735	1.080
1000	1.240	1.63	0.793	1.131
1500	1.282	1.68	0.836	1.14

OXYGEN OVERVOLTAGES.—(Continued)

Milliamp per cm <sup>2</sup>	Overvoltage in volt			
	Smooth Pt	Platinized Pt	Smooth Ni	Spongy Ni
1	0.721	0.398	0.353	0.414
5	0.80	0.480	0.461	0.511
10	0.85	0.521	0.519	0.563
20	0.92	0.561		
50	1.16	0.605	0.670	0.653
100	1.28	0.638	0.726	0.687
200	1.34		0.775	0.714
500	1.43	0.705	0.821	0.740
1000	1.49	0.766	0.853	0.762
1500	1.38	0.786	0.871	0.759

EFFECT OF TEMPERATURE ON OVERVOLTAGE

Average temperature coefficient of hydrogen overvoltage on smooth electrodes in 2N H<sub>2</sub>SO<sub>4</sub> for temperature range 0 to 75°C (8); cf. (11, 12, 13).

Electrode	Current density, amp/cm <sup>2</sup>	dE/dT, mv(millivolt)/°C
Silver.....	0.40	2.0
	0.10	2.4
	0.01	2.5
Copper.....	0.40	2.4
	0.10	2.6
	0.01	3.1
Nickel.....	0.10	2.4
	0.01	2.6
Lead.....	0.40	1.8
	0.10	2.0
	0.05	1.6

For other articles each containing a few measurements, see (10.5, 11, 12, 13).

EFFECT OF PRESSURE ON OVERVOLTAGE (1)

Hydrogen overvoltage increases with reduction in pressure by the same amount that the reversible hydrogen electrode potential increases, i.e., potential of polarized cathode measured against an electrode such as the Hg: Hg<sub>2</sub>SO<sub>4</sub> which does not change with pressure, is constant. For Hg, Ni, and Pb, very low current density, pressure range 20 to 750 mm, 20°C. Confirmed by Knobel (6) for smooth lead, copper and nickel, and for platinized platinum each at current densities of 0.01, 0.1, and 1.0 amp per cm<sup>2</sup>, and for pressure range 22 mm to 760 mm Hg, 25°C.

Divergent results (4).

Oxygen overvoltage, 100 atm. (9) decrease of 0.02 volt from value at 1 atm.

LITERATURE

(For a key to the periodicals see end of volume)

- (1) Bircher and Harkins, 1, 45: 2890; 23. (2) Dunnill, 4, 119: 1081; 21. (3) Glasstone, 58, 111: 775; 23. (4) Goodwin and Wilson, 78, 40: 173; 21. (5) Knobel, 1, 46: 2613; 24. (6) Knobel, 1, 46: 2751; 24. (7) Knobel, Caplan and Eiseman, 78, 48: 55; 23. (8) Knobel and Joy, 78, 44: 443; 23. (9) Newbery, 4, 108: 2419; 14. (10.5) Onoda, 83, 162: 57; 27. 165: 79; 27. (11) Newbery, 83, 18 I: 126; 19. (12) Pring and Curson, 83, 7: 237; 12. (13) Rideal, 1, 42: 94; 20. (14) Tafel, 7, 50: 641; 05. (15) Tartar and Keyes, 1, 44: 557; 22.



## ELECTRICAL AND OPTICAL PROPERTIES OF SILICA

ROBERT B. SOSMAN

## Dielectric Constant (12, 16, 27, 28.1, 38, 67, 76, 79, 81, 85)

	Most probable value	Limits between which the true value certainly lies
Quartz, axis $\parallel$ to direction of field.	4.6	4.5 and 5.0
Quartz, axis $\perp$ to direction of field.	4.5	4.2 and 4.7
Difference ( $\parallel$ ) - ( $\perp$ ).....	+0.1	+0.1 and +0.4
Vitreous silica.....	3.75	3.2 and 3.9

## Electrical Resistivity

Unit, ohm-cm (1, 7, 12, 16, 22, 26, 35, 39, 67, 68, 84, 86, 90)

$t, ^\circ\text{C}$	Quartz		Vitreous silica†			
	$\parallel$ to axis*	$\perp$ to axis	$t, ^\circ\text{C}$	ohm-cm	$t, ^\circ\text{C}$	ohm-cm
20	$0.1 \times 10^{15}$	$20 \times 10^{15}$	20	$10 \times 10^{18}$	700	$10 \times 10^6$
100	$0.8 \times 10^{12}$		100	$1 \times 10^{18}$	800	$4 \times 10^6$
200	$70 \times 10^9$		200	$10 \times 10^{16}$	900	$2 \times 10^6$
300	$60 \times 10^6$		300	$0.2 \times 10^{12}$	1000	$1 \times 10^6$
1000	$50 \times 10^3$	$100 \times 10^3$	400	$5 \times 10^9$	1100	$0.7 \times 10^6$
1300	$5 \times 10^3$	$10 \times 10^3$	500	$0.3 \times 10^9$	1200	$0.5 \times 10^6$
			600	$60 \times 10^6$	1300	$0.4 \times 10^6$

\* This is natural quartz, whose axial conductance is due mainly to impurities; the true axial resistivity of pure quartz is not known.

† Cf. Seemann (2, 31: 119; 28), who finds lower values

## Piezoelectric Constants of Quartz (14, 15, 18, 33, 63, 69, 73, 74)

Pressure in baryes (dynes per  $\text{cm}^2$ ); charge in absolute electrostatic units per  $\text{cm}^2$

$d_{11}$  (principal coefficient).....  $-69 \times 10^{-9}$

$d_{14}$ .....  $+17 \times 10^{-9}$

See also p. 211.

## Magnetic Susceptibility (13, 41, 89, 94)

Quartz in vacuo, at  $20^\circ\text{C}$ 

Volume-susceptibility, $10^6\kappa$		Mass-susceptibility, $10^6\kappa_1$	
$\parallel$ to axis	$\perp$ to axis	$\parallel$ to axis	$\perp$ to axis
-1.21	-1.20	-0.457	-0.452

## Optical Constants (5, 10, 20, 25, 28, 50, 55, 64, 78, 91, 93)

Room temperature

	Low-quartz	Low-tridymite	Low-cristobalite	Vitreous silica
Indices of refraction for sodium light $\left\{ \begin{array}{l} n_\alpha \\ n_\beta \\ n_\gamma \end{array} \right.$	1.544 ( $n_\alpha$ )	1.469	1.484	1.459 ( $n$ )
	1.553 ( $n_\alpha$ )	1.47	Near 1.487	
Birefringence for sodium light ( $n_\gamma - n_\alpha$ ).....	0.009	0.004	0.003 or higher	0
Constringence, $\nu$ .....	{ For $\nu$ , 69.9 } Positive		Negative	67.6
Optical character.....	Positive	Positive	Negative	
Optical orientation.....	$\alpha = n_\gamma$			
Optical character of elongation.....	Positive	Negative		
Optic axial angle, $2V_\gamma$ .....	0	35 to 43°	>90°	
Apparent optic axial angle, $2V_\gamma$ .....	0	56 to 66°	>90°	
Optical rotatory power, $\alpha_D$	21.72° per mm			0.000°

## Refractive Index

At  $18^\circ$ , IN AIR AT SAME TEMPERATURE (6, 9, 19, 24, 29, 30, 34, 47, 48, 49, 51, 55, 58, 60, 61, 70, 71, 76, 87, 92)

Radiating element	Wave-length in air at $15^\circ$ , $m\mu$	$N_\omega$ , quartz	$N_e$ , quartz	$N$ , vitreous
Al.....	185.467	1.67578	1.68997	1.57436
Al.....	193.583	1.65999	1.67343	1.55999
Au.....	200.06	1.64927	1.66227	
Zn.....	202.55	1.64557	1.65842	1.54727
Au.....	204.448	1.64288	1.65562	
Au.....	211.07	1.63432	1.64671	
Cd.....	214.439	1.63039	1.64262	1.53386
Cd.....	219.462	1.62497	1.63698	1.52507
Cd.....	226.503	1.61818	1.62992	1.52308
Cd.....	231.288	1.61401	1.62559	1.51941
Au.....	242.796	1.60525	1.61650	
Au.....	250.329	1.60032	1.61139	1.50745
Cd.....	257.304	1.59622	1.60714	1.50379
Al.....	263.155	1.59309	1.60389	
Cd.....	274.867	1.58752	1.59813	1.49617
Au.....	291.358	1.58098	1.59136	
Sn.....	303.412	1.576955	1.58720	1.48594
Au.....	312.279	1.57433	1.584485	
Cd.....	325.253	1.570915	1.58095	
Cd.....	340.365	1.56747	1.577385	1.47867
Al.....	358.68	1.563915	1.573705	
Ca.....	396.848	1.55813	1.56772	1.47061
Hg.....	404.656	1.557156	1.56671	1.46968
H.....	410.174	1.556502	1.566031	
H.....	434.047	1.553963	1.563405	1.46690
Hg.....	435.834	1.553790	1.563225	1.46675
Cd.....	467.815	1.551027	1.560368	1.46435
Cd.....	479.991	1.550118	1.559428	1.46355
H (solar line "F").....	486.133	1.549683	1.558979	1.46318
Cd.....	508.582	1.548229	1.557475	1.46191
Mg (solar line "b <sub>1</sub> ").....	518.362	1.547651	1.556877	
Cd.....	533.85	1.546799	1.555996	1.46067
Hg.....	546.072	1.546174	1.555350	1.46013
Hg.....	579.066	1.544667	1.553791	
He.....	587.563	1.544316	1.553428	
Na (mean).....	589.29	1.544246	1.553355	1.45845
Au.....	627.82	1.542819	1.551880	
Cd.....	643.847	1.542288	1.551332	1.45674
H (solar line "C").....	656.278	1.541899	1.550929	1.45640
He.....	667.815	1.541553	1.550573	
Li.....	670.786	1.541466	1.550483	
He.....	706.520	1.540488	1.549472	1.45517
He.....	728.135	1.539948	1.548913	
K.....	766.494	1.539071	1.548005	
Rb.....	794.763	1.538478	1.547392	1.45340
O.....	844.67	1.537525	1.54640	
	1000.00	1.53503	1.54381	
Hg.....	1014.06	1.53483	1.54360	
He.....	1083.03	1.53387	1.54260	
	1200.00	1.53232	1.54098	
	1300.00	1.53102	1.53962	
	1400.00	1.52972	1.53826	



## Refractive Index.—(Continued)

Radiating element	Wave-length in air at 15°, mμ	N <sub>ω</sub> , quartz	N <sub>e</sub> , quartz	N, vitreous
Hg.....	1529.61	1.52800	1.53646	
	1600.00	1.52703	1.53545	
	1800.00	1.52413	1.53242	
He.....	2058.20	1.51998	1.52814	
	2500.00	1.51156	1.5195	
	3000.00	1.49962	1.5070	

CHANGE OF THE REFRACTIVE INDICES OF QUARTZ (PER DEGREE,  
FOR RANGE 20 TO 100°C) (56)

Approximate wave-length, mμ	Change of absolute index		Change of index in air	
	10 <sup>6</sup> Δn <sub>e</sub>	10 <sup>6</sup> Δn <sub>ω</sub>	10 <sup>6</sup> ΔN <sub>e</sub>	10 <sup>6</sup> ΔN <sub>ω</sub>
202	+1.29	+1.84	+2.67	+3.21
206	+0.63	+1.19	+1.98	+2.53
210	+0.08	+0.59	+1.45	+1.93
214	-0.49	-0.07	+0.83	+1.24
219	-1.05	-0.57	+0.27	+0.74
224	-1.79	-1.13	-0.48	+0.17
226	-2.04	-1.36	-0.75	-0.08
228	-2.22	-1.55	-0.93	-0.27
231	-2.41	-1.80	-1.12	-0.52
257	-3.89	-3.09	-2.65	-1.86
274	-4.44	-3.55	-3.23	-2.35
288	-5.06	-3.99	-3.85	-2.79
298	-5.34	-4.29	-4.15	-3.11
313	-5.68	-4.65	-4.50	-3.48
325	-5.87	-4.69	-4.69	-3.52
340	-6.17	-5.08	-5.01	-3.93
361	-6.40	-5.32	-5.25	-4.18
441	-7.05	-5.87	-5.93	-4.75
467	-7.15	-5.96	-6.01	-4.85
480	-7.22	-6.10	-6.10	-4.99
508	-7.29	-6.25	-6.16	-5.14
589	-7.54	-6.50	-6.42	-5.39
643	-7.64	-6.60	-6.53	-5.49

CHANGE OF REFRACTIVE INDEX OF VITREOUS SILICA PER DEGREE,  
FOR RANGE 20 TO 100°C (52)

Radiating element	Approx. wave-length	Change of absolute index, 10 <sup>6</sup> Δn	Change of index in air, 10 <sup>6</sup> ΔN
Al.....	185	23.19	24.61
Al.....	186	22.71	24.13
Al.....	193	20.80	22.17
Al.....	198	19.65	21.00
Zn.....	206	18.32	19.64
Zn.....	210	17.50	18.81
Cd.....	214	17.28	18.57
Zn.....	215	17.01	18.30
Cd.....	219	16.66	17.94
Cd.....	224	15.70	16.97
Cd.....	226	15.90	17.16
Cd.....	231	16.99	18.24
Cd.....	232	15.26	16.51
Cd.....	257	13.74	14.95
Cd.....	274	13.01	14.20
Cd.....	288	12.32	13.49

## CHANGE OF REFRACTIVE INDEX OF VITREOUS SILICA.—(Continued)

Radiating element	Approx. wave-length	Change of absolute index, 10 <sup>6</sup> Δn	Change of index in air, 10 <sup>6</sup> ΔN
Cd.....	298	12.25	13.41
Cd.....	325.5	11.99	13.14
Cd.....	346	11.41	12.55
Cd.....	361	11.27	12.40
Cd.....	441	10.41	11.51
Cd.....	480	10.20	11.29
Cd.....	508	10.21	11.29

VITREOUS SILICA AT VARIOUS TEMPERATURES; ABSOLUTE INDEX  
OF REFRACTION CALCULATED FROM DATA OF RINNE (71)

Temp., °C	He, blue λ = 471.315mμ	He, green 501.568	He, yellow 587.563	He, red 667.815
-160	1.4635	1.4617	1.4581	1.4559
-64	1.4641	1.4624	1.4586	1.4563
+18	1.4649	1.4629	1.4592	1.4569
130	1.4660	1.4642	1.4604	1.4579
235	1.4675	1.4654	1.4616	1.4591
365	1.4692	1.4672	1.4633	1.4608
475	1.4708	1.4689	1.4649	1.4625
590	1.4722	1.4703	1.4663	1.4639
1000		1.4772	1.4729	1.4706

See further p. 343.

## Dispersion

CONSTANTS IN THE FORMULA:  $n^2 = m + \frac{m_1 \lambda^2}{\lambda^2 - \lambda_1^2} - k \lambda^2$ ;  
λ and λ<sub>1</sub> in μ at 18°, in vacuo (53, 54)

	m	m <sub>1</sub>	λ <sub>1</sub>	k
Quartz, n <sub>e</sub> .....	1.43813	0.95014	0.106692	0.01723
Quartz, n <sub>ω</sub> (1904).....	1.42919	0.93173	0.105805	0.01635
Quartz, n <sub>ω</sub> (1906).....	1.40090	0.95650	0.10495	0.01093
Vitreous, n.....	1.36112	0.74655	0.107044	0.01350

## EFFECT OF TEMPERATURE, CHANGE PER DEGREE C (54)

	10 <sup>6</sup> Δm	10 <sup>6</sup> Δm <sub>1</sub>	10 <sup>6</sup> Δλ <sub>1</sub> in μ	Δk
Quartz, n <sub>e</sub> .....	67.838	-80.195	6.3200	0
Quartz, n <sub>ω</sub> .....	69.390	-80.048	6.3200	0
Vitreous silica.....	69.400	-41.832	6.3200	0

## Optical Rotation

QUARTZ AT 20°C (2, 6, 8, 23, 31, 32, 36, 37, 45, 46, 48, 80, 82);  
see also Vol. II, p. 336

Radiating element	Wave-length in air at 15°, mμ	Deg., α/mm
Cd.....	226.503	201.9
Cd.....	231.288	190.5
Au.....	242.796	166.9
Au.....	250.329	153.9
Cd.....	274.867	121.10
Sn.....	303.412	95.02
Cd.....	340.365	72.45
Fe.....	348.534	68.585
Ca.....	396.848	51.115
Hg.....	404.656	48.945
H.....	410.174	47.495
H.....	434.047	41.924

Continued on p. 343



## Refractive Index.—(Continued from p. 342)

QUARTZ AT VARIOUS TEMPERATURES, AS MEASURED BY RINNE AND KOLB (72) AND RECALCULATED AS ABSOLUTE INDICES  
Extraordinary index,  $n_e$ 

Solar line	Wave length, $m\mu$	-140°	-45°	+23°	115°	212°	305°	410°	550°	580°	650°	765°
G' (H <sub>γ</sub> ).....	434.047		1.5633	1.5634	1.5629	1.5623	1.5615	1.5598	1.5551	1.5503	1.5521	1.5532
(d).....	466.8		1.5609	1.5608	1.5603	1.5597	1.5588	1.5572	1.5526	1.5478	1.5492	1.5506
F.....	486.133	1.5594	1.5594	1.5593	1.5589	1.5581	1.5573	1.5558	1.5512	1.5464	1.5475	1.5490
(c).....	495.75		1.5587	1.5587	1.5582	1.5576	1.5567	1.5552	1.5503	1.5456	1.5468	1.5481
b <sub>1</sub> .....	517.27		1.5574	1.5574	1.5568	1.5562	1.5553	1.5538	1.5488	1.5442	1.5454	1.5469
D <sub>2</sub> .....	588.997	1.5541	1.5539	1.5537	1.5532	1.5526	1.5515	1.5499	1.5451	1.5405	1.5417	1.5431
α.....	627.8	1.5526	1.5525	1.5522	1.5517	1.5510	1.5500	1.5486	1.5437	1.5389	1.5403	1.5416
C.....	656.278		1.5516	1.5513	1.5508	1.5502	1.5491	1.5475	1.5427	1.5380	1.5393	1.5406
B.....	687.2	1.5506	1.5506	1.5504	1.5499	1.5492	1.5481	1.5466	1.5419	1.5369	1.5383	1.5397
a.....	718.9		1.5499	1.5495	1.5490	1.5483	1.5472	1.5458	1.5408	1.5362	1.5375	1.5388

Ordinary index,  $n_o$ 

Solar line	Wave length, $m\mu$	-140°	-45°	+23°	115°	212°	305°	410°	550°	580°	650°	765°
G' (H <sub>γ</sub> ).....	434.047		1.5539	1.5540	1.5536	1.5531	1.5523	1.5510	1.5469	1.5425	1.5439	1.5454
(d).....	466.8		1.5515	1.5514	1.5511	1.5506	1.5498	1.5483	1.5442	1.5400	1.5414	1.5429
F.....	486.133	1.5504	1.5501	1.5500	1.5497	1.5491	1.5483	1.5469	1.5426	1.5385	1.5399	1.5414
(c).....	495.75		1.5494	1.5494	1.5491	1.5485	1.5477	1.5465	1.5421	1.5379	1.5393	1.5406
b <sub>1</sub> .....	517.27		1.5481	1.5481	1.5476	1.5472	1.5463	1.5452	1.5407	1.5363	1.5377	1.5392
D <sub>2</sub> .....	588.997	1.5449	1.5448	1.5446	1.5441	1.5437	1.5428	1.5414	1.5370	1.5329	1.5341	1.5356
α.....	627.8	1.5434	1.5434	1.5431	1.5427	1.5422	1.5413	1.5401	1.5357	1.5314	1.5328	1.5340
C.....	656.278		1.5425	1.5423	1.5418	1.5414	1.5405	1.5390	1.5349	1.5304	1.5319	1.5331
B.....	687.2	1.5417	1.5416	1.5414	1.5410	1.5405	1.5395	1.5382	1.5337	1.5296	1.5309	1.5321
a.....	718.9		1.5408	1.5405	1.5401	1.5396	1.5386	1.5374	1.5327	1.5288	1.5301	1.5313

## Optical Rotation.—(Continued from p. 342)

Radiating element	Wave-length in air at 15°, $m\mu$	Deg., $\alpha/mm$
Hg.....	435.834	41.548
Cd.....	467.815	35.601
H (solar line "F").....	486.133	32.761
Cd.....	508.582	29.728
Hg.....	546.072	25.535
Na (mean).....	589.29	21.724
Cd.....	643.847	18.023
Li.....	670.786	16.535
He.....	728.135	13.924
Rb.....	794.763	11.589
Hg.....	1014.06	6.976
	1200.00	4.889
Hg.....	1529.61	2.930
He.....	2058.20	1.527
	2500.00	0.972

## CHANGE OF THE ROTATORY POWER OF QUARTZ WITH TEMPERATURE

Ratio of the measured rotation at temperature  $t$  to the measured rotation of the same plate at 0°C (2, 3, 31, 40, 42, 43, 57)

$t$ , °C	$\alpha_t/\alpha_0$	$t$ , °C	$\alpha_t/\alpha_0$	$t$ , °C	$\alpha_t/\alpha_0$
-200	0.979	200	1.031	600	1.164
-100	0.988	300	1.050	700	1.166
0	1.000	400	1.071	800	1.167
+ 50	1.007	500	1.100	900	1.169
100	1.014	573	1.132	1000	1.171
			1.163		

## Reflectivity

Wave-lengths of the maxima of reflection by quartz, as given by various observers (11, 44, 59, 65, 75, 77.1, 88)

Observer	Quartz, $\omega$					
Nichols (1897).....	8.42	8.80				
Rubens and Nichols.....	8.50	9.02				20.75
Rosenthal (1899).....	8.49	9.03				
Coblentz (1906).....	8.48		12.5			
Coblentz (1908).....	8.3-8.5	9.02				
Reinkober (1910).....	8.40*	9.02†	9.20‡	12.52	14.55	
Trowbridge and Wood.....	8.41	8.90				
Liebisch and Rubens.....						21.0 26.0
Quartz, $\epsilon$						
Reinkober (1910).....	8.40*	8.70†	9.02‡	12.87		
Liebisch and Rubens.....						19.7 27.5
Vitreous silica						
Coblentz (1908).....	8.3	8.8				
Reinkober (1910).....	8.30	8.90		12.6	14.6	
Liebisch and Rubens.....						21.2 26.8

\* Center of mass of two maxima, one at 8.35, and one at 8.50 (weak).

† Center of mass of two maxima, one at 8.90, and one at 9.05.

‡ Weak.

## Verdet Constant

## SODIUM LIGHT AT ROOM TEMPERATURE

Values of  $10^3\omega$ .  $\omega = \alpha/lH$ .  $\alpha$  in minutes,  $l$  in cm,  $H$  in gilbert per cm.

Quartz, 17; vitreous, 15. Temperature coefficient about +0.01% per degree C (4, 45, 83).



DISPERSION OF THE VERDET CONSTANT

Source	Wave-length, mμ	Quartz, Verdet constant, 10 <sup>3</sup> ω (4)	
		At 20°	At 96°
Cd, 25.....	219.462	158.66	
Cd, 18.....	257.304	107.90	
Cd, 9.....	361.25	46.17	
Cd, 6.....	467.815	27.50	27.72
Cd, 5.....	479.991	25.74	
Cd, 4.....	508.582	22.57	
D.....	589.29	16.64	16.82
Cd, 1.....	643.847	13.68	13.79

DISPERSION-RATIOS FOR VERDET CONSTANT OF QUARTZ

Radiating element	Wave-length, mμ	Ratio to D line			
		(4)	(21)	(45)	(37)
Cd <sub>25</sub> .....	219.462	9.534			
Cd <sub>18</sub> .....	257.304	6.484			
Cd <sub>9</sub> .....	361.25	2.775			
Hg.....	404.656		2.137		
Hg.....	435.834		1.852	1.912	
Cd <sub>6</sub> .....	467.815	1.653			
Cd <sub>5</sub> .....	479.991	1.547		1.477	
Hg.....	491.60		1.456		
Cd <sub>4</sub> .....	508.582	1.356		1.372	
Hg.....	546.072		1.171	1.175	
	549.5				1.158
Hg.....	579.066		1.041		
D.....	589.29	1.000	1.000	1.000	1.000
	600				0.963
Cd <sub>1</sub> .....	643.847	0.822			
H.....	656.278		0.800		
Li.....	670.786			0.760	
	700				0.690
	800				0.529
	900				0.415
	1000				0.330
	1100				0.269
	1200				0.224
	1300				0.1915
	1400				0.1663
	1500				0.1444
	1600				0.1266
	1700				0.1125
	1800				0.0987
	1900				0.0869
	2000				0.0761
	2140				0.0627

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(For a key to the periodicals see end of volume)

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## MAGNETISM

COMPLETE INDEX	INDEX COMPLET	GESAMT INDEX VERZEICHNIS	INDICE COMPLETO	PAGE
Atomic and molecular data, theories of magnetism.	Données atomiques et moléculaires, théories du magnétisme.	Atom- und Molekular-Daten, Theorien des Magnetismus.	Dati atomici e molecolari, teorie del magnetismo.	345
Paramagnetic and diamagnetic data.	Données paramagnétiques et diamagnétiques.	Paramagnetische und diamagnetische Daten.	Dati diamagnetici e paramagnetici.	354
Ferromagnetism.	Ferromagnétisme.	Ferromagnetismus.	Ferromagnetismo.	366
Galvanomagnetic and thermomagnetic effects.	Effets galvanomagnétiques et thermomagnétiques.	Galvanomagnetische und thermomagnetische Effekte.	Effetti galvanomagnetici e termomagnetici.	414
Magneto-optics.	Magnéto-optique.	Magnetooptik.	Magnetoottica.	425
Magnetostriction.	Magnétostriktion.	Magnetostriktion.	Magnetostrizione.	439
Terrestrial magnetism.	Magnétisme terrestre.	Erdmagnetismus.	Magnetismo terrestre.	445

## ATOMIC AND MOLECULAR DATA IN RELATION TO THEORIES OF MAGNETISM

S. J. BARNETT

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Symbols and units.	Symboles et unités.	Symbole und Einheiten.	Simboli e unità.	346
Magneton or magnetic elements.	Magnétons ou éléments magnétiques.	Magnetonen oder magnetische Elemente.	Magnetoni o elementi magnetici.	346
Molecular gyromagnetic effects.	Effets moléculaires gyromagnétiques.	Molekularer gyromagnetischer Effekt.	Effetti molecolari giromagnetici.	347
Magnetism and structure.	Magnétisme et structure.	Magnetismus und Struktur.	Magnetismo e struttura.	
Effect of number of electrons.	Effet du nombre des électrons.	Einfluss der Elektronenzahl.	Effetto del numero di elettroni.	347
Effect of distribution of electrons and electron orbits.	Effet de la distribution des électrons et des orbites électroniques.	Einfluss der Elektronenverteilung und der Elektronenbahnen.	Effetto della distribuzione degli elettroni e delle orbite elettroniche.	347
Effect of crystal structure.	Effet de la structure cristalline.	Einfluss der Kristallstruktur.	Effetto della struttura cristallina.	347
Additivity relations.	Relations d'additivité.	Additivitätsbeziehungen.	Relazioni d'addittività.	
Simple additivity.	Simple additivité.	Einfache Additivität.	Addittività semplice.	349
Pascal's relation.	Relation de Pascal.	Pascal-Beziehung.	Relazione di Pascal.	349
Theories of diamagnetism.	Théories du diamagnétisme.	Theorien des Diamagnetismus.	Teorie del diamagnetismo.	
Weber-Langevin theory.	Théorie de Weber-Langevin.	Weber-Langevin-Theorie.	Teoria di Weber-Langevin.	349
Pauli theory.	Théorie de Pauli.	Pauli-Theorie.	Teoria di Pauli.	350
Atomic radii.	Rayons atomiques.	Atomischer Halbmesser.	Raggi atomici.	350
Theories of paramagnetism.	Théories du paramagnétisme.	Theorien des Paramagnetismus.	Teorie del paramagnetismo.	
Susceptibility independent of temperature.	Susceptibilité indépendante de la température.	Suszeptibilität, unabhängig von der Temperatur.	Suscettività indipendente dalla temperatura.	350
Susceptibility dependent on temperature.	Susceptibilité dépendant de la température.	Suszeptibilität, abhängig von der Temperatur.	Suscettività dipendente dalla temperatura.	
Langevin's theory.	Théorie de Langevin.	Langevin-Theorie.	Teoria di Langevin.	350
Weiss's generalization of Langevin's theory.	Généralisation de Weiss apportée à la théorie de Langevin.	Weiss'sche Verallgemeinerung der Langevin-Theorie.	Generalizzazione di Weiss della teoria di Langevin.	350
Magnetic moments of molecules and ions of paramagnetic substances.	Moments magnétiques des molécules et ions des substances paramagnétiques.	Magnetische Momente von Molekülen und Ionen paramagnetischer Stoffe.	Momenti magnetici di molecole e ioni di sostanze paramagnetiche.	351
Energy quantization theories.	Théories de la quantification de l'énergie.	Theorien über die Energiequantelung.	Teorie sulla quantizzazione dell'energia.	352
Spatial quantization theories.	Théories de la quantification spatiale.	Raumquantelungstheorien.	Teorie sulla quantizzazione spaziale.	352



A body can be magnetized either by placing it in a magnetic field or by rotating it in a neutral region (p. 347). The magnetization acquired in a magnetic field results from the superposition of two effects, either of which may practically vanish: (1) A *magnetic* effect, consisting in an alignment, more or less parallel to the applied magnetic field, of the axes of certain permanent, or approximately permanent, *magnetic elements* constituting parts of the molecules; and (2) a *diamagnetic* effect, fundamentally identical with the induction of an electric current in a conductor (88). In *diamagnetic* substances  $\chi$  is negative, small, independent of  $H$  and, in many cases, independent of temperature and certain other physical conditions. *Magnetic* substances, for which  $\chi$  is positive, are either *paramagnetic* or *ferromagnetic*. In *paramagnetic* substances  $\chi$  is small and independent of  $H$  at ordinary temperatures and in weak fields. In *ferromagnetic* substances  $\chi$  is relatively large and depends upon  $H$ , unless  $H$  is very small. When its temperature is sufficiently increased, every ferromagnetic substance becomes transformed into a paramagnetic substance. The temperature at which this change occurs is called the *temperature of transformation* or *Curie point* ( $\Theta$ ) for the substance. The data given in this report refer chiefly to paramagnetic and diamagnetic substances, because only a few pertinent quantitative atomic and molecular data are available for ferromagnetic substances.

SYMBOLS AND UNITS

Unless another is indicated, the basic unit in every case is the appropriate cgsu unit. Symbols which are frequently used throughout the Tables are defined in Vol. I, p. 16; those used in only a single section will be defined where used.

- A Atomic weight.
  - a Constant in Langevin's equation (p. 350).
  - B Number of Bohr magnetons per basal unit;  $[\mu] = B[\mu]_B$ .
  - e Electric charge; usually, but not necessarily, it is numerically equal to the "electronic charge,"  $e$ .
  - H Intensity of magnetic field.
  - j Angular momentum of the body, or system, under consideration.
  - M Molecular weight.
  - m Mass.
  - $m_0$  Electronic mass at low velocity.
  - $N_0$  Avogadro's number.
  - R Gas constant per gram-mole.
  - $R_0$   $2m_0/e$ .
  - r Radius.
  - T Absolute temperature, °K.
  - W Number of Weiss magnetons per basal unit;  $[\mu] = W[\mu]_W$ .
  - Z Atomic number.
  - $\Theta$  Curie point. Temperature-constant in Weiss's relation.
  - $[\mu]$  Magnetic moment of the system under consideration.
  - $[\mu_0]$  Magnetic moment of elementary magnetic unit.
  - $\Sigma$  Sign of summation.
  - $\sigma$  Specific magnetization = magnetic moment per unit of mass.
  - $\sigma_{\parallel}$  Value of  $\sigma$  when axes of all the elementary magnetic moments are parallel.
  - $\chi$  Specific susceptibility = susceptibility divided by density.
- Subscripts:  $a, m$  indicates the quantity is referred to the gram-atom, gram-mole.  $B, W$  indicates the quantity is expressed in the Bohr magneton, the Weiss magneton, as unit moment.

Magnetons or Magnetic Elements

The term *magneton* has been applied both to the complete magnetic element within the atom or molecule, and to the ultimate magnetic units of which the element may be constituted. Of the various magnetons which have been proposed, four will be considered here; the first three are based upon theory, the fourth entirely upon experiment.

*Spinning Electron* (1, 32, 63, 97, 115).—The element is the rotating spherical electron. The ratio of the angular momentum ( $j$ ) to the magnetic moment  $[\mu]$  is  $(j/[\mu])_s = m_s/e$  if the charge is distributed uniformly over the surface, and  $(j/[\mu])_v = 5m_s/7e$  if the charge is distributed uniformly throughout the volume;  $m_s$  and  $m_v$  are the inertias of the electron in the two cases. If  $r$  = radius of the electron,  $m_s = 2e^2/3r$ .  $m_v = 4e^2/5r$ .

*Bohr Magneton* (104).—The electron is revolving in a fixed orbit;  $j/[\mu_0] = 2m_0/e(\equiv R_0) = -1.13 \times 10^{-7}$  for a negative electron. On Bohr's theory, the least value of  $j$  is  $h/2\pi$ , and the corresponding value of  $[\mu_0]$  is Bohr's magneton  $[\mu_0]_B = eh/4\pi m_0 = 9.23 \times 10^{-21}$ . The Bohr gram-magneton  $[\mu_0]_B$  is defined as  $N_0[\mu_0]_B = 5593$  (28, 104); if there is but one such electron orbit per atom,  $[\mu_0]_B = [\mu_0]$ .

*Sommerfeld Magneton* (104).—On Sommerfeld's spectroscopic theory, the atomic moment of an atom is  $[\mu] = g[\mu_0]_B$ , where  $g$  is Landé's "splitting factor," and the angular momentum of the atom is  $j = j_1 h/2\pi$ . The quantities  $j$  and  $g$  are derived from spectroscopic data, and the product  $gj_1$  is known as the spectroscopic magneton number of the atom in the given state.

The magnetic moment of the free neutral atom of a metal may be determined directly from the effect of an intense and non-uniform magnetic field upon a high velocity stream of the vaporized metal in the atomic state (method of Gerlach and Stern) (45, 46, 47, 68, 92, 110, 137). The experimental error in the magneton number ( $[\mu]/[\mu_0]_B$ ), so determined, ranges from 0.02 to 0.3 or 0.4.

TABLE 1.—COMPARISON OF MAGNETON NUMBERS ( $B$ ) OBTAINED BY DIFFERENT METHODS (45, 46, 47, 68, 92, 110, 137)

$[\mu] = B[\mu_0]_B$ ;  $B_{GS}, B_S$  = value of  $B$  obtained by the Gerlach and Stern, and by the spectroscopic method, respectively

Atom....	H	Na	K	Cu	Ag	Au	Zn	Cd	Hg
$B_{GS}$ .....	1	1	1	1	1	1	0	0	0
$B_S$ .....	1	1	1	1	1	1	0	0	0

Atom.....	Tl	Sn	Pb	Sb	Bi	Te	Ni	Fe
$B_{GS}$ .....	$\frac{1}{2}$	0	0	0	(?)	0	$\leq 2$	0
$B_S$ .....	$\frac{1}{2}$	0	0	0	(?)	(?)	5	*

\* Large.

*Weiss Magneton* (11, 50, 89, 93, 120, 126).—At very low temperatures,  $\chi_0$ , for both Fe and Ni, approaches asymptotically a definite maximum as the intensity of the field is increased and the temperature is decreased. The limiting values are  $1123.6 \times 11$  for Fe, and  $1123.3 \times 3$  for Ni. The value 1123.5 is the magnetic moment of the gram-magneton of Weiss,  $[\mu]_W$ . At very low temperatures, the atoms of Fe and Ni contain, respectively, 11 and 3 Weiss magnetons. The moment of the elementary Weiss magneton is defined as  $[\mu_0]_W = 1123.5/N_0 = 1.854 \times 10^{-21}$ . Within less than the experimental error, the magnetic moments of the Weiss magnetons are  $\frac{1}{5}$  as great as those of the corresponding Bohr magnetons.

TABLE 2.—ATOMIC AND MOLECULAR MAGNETIC MOMENTS  $[\mu]$  OF FERROMAGNETIC SUBSTANCES AT LOW TEMPERATURES:

METHOD OF WEISS

$[\mu] = W[\mu_0]_W$

	Fe	Fe*	Fe†	Ni†	FeNi <sub>2</sub>
W.....	11.00	11.00	10.00	3.00	20.0
Lit.....	(120, 126)	(90)	(93)	(90, 120, 126)	(90)

	Fe <sub>2</sub> Ni <sub>2</sub>	Fe <sub>2</sub> Ni	Co*	Co†	Fe <sub>2</sub> Co
W.....	27.0	27.0	8.92	8.97	36.1
Lit.....	(90)	(90)	(11)	(93)	(93)

\* By extrapolation from data for Ni alloys.

† By extrapolation from data for Fe-Co alloys.

‡ See also p. 351.



## Molecular Gyromagnetic Effects

**Magnetization by Rotation** (Barnett) (3, 7).—In effect, each magneton is a gyrostat with a magnetic moment parallel to the axis of rotation; when a body containing magnetons is rotated, the directions of their magnetic moments tend to become parallel to the axis of rotation of the body. For a circular cylinder making  $n$  rotations per sec about its axis of figure, the resultant magnetic moment ( $M$ ), so produced parallel to the axis, is  $M = C\lambda n = CH$ , where  $C$  is a constant,  $\lambda = 2\pi j/[\mu]$ , and  $H$  is the intensity of the axial magnetic field that would produce the same moment ( $M$ ) without rotation;  $\lambda (=H/n)$  is called the specific magnetic intensity of rotation for the substance of the rod. On the classical theory, if the magneton is an electron in a Bohr orbit,  $\lambda = 2\pi j/[\mu_0] = 4\pi m_0/e = 2\pi R_0 = -7.10 \times 10^{-7}$  gauss/rotation per sec. If the magneton is a spherical electron with uniform surface charge (Lorentz) spinning about a diameter,  $\lambda = -3.55 \times 10^{-7}$  gauss/rotation per sec. Results of experiments are given in Table 3.

TABLE 3.—MAGNETIZATION BY ROTATION

$\lambda$  = specific magnetic intensity of rotation  $= 2\pi j/[\mu]$ . For Bohr magneton,  $j/[\mu] = R_0$ ; for spinning electron with surface charge,  $j/[\mu] = R_0/2$ .  $2\pi R_0 = 4\pi m_0/e = -7.10 \times 10^{-7}$  gauss/rotation per sec; unit of  $\lambda (=H/n) = 10^{-7}$  gauss/rotation per sec.

Material	Notes	$-\lambda$	Material	Notes	$-\lambda$
Steel.....	*	3.6	Heusler alloy..	†	3.62
Steel.....	†	3.4	Permalloy.....	80% Ni†	3.78
Iron.....	6 rods†	3.79	Ni-Fe.....	25% Ni†	3.63
Steel.....			Co-Fe.....	35% Co†	3.83
Nickel.....	2 rods†	3.69	Co-Ni.....	54% Co†	3.83
Cobalt.....	†	3.84			

Weighted mean of observations (†) of 1923,  $3.76 \pm 0.07$ .

Hence  $j/[\mu] = (3.76/7.10)R_0 = 0.529R_0 = 1.06m_0/e$ .

\* Observations of 1914, method of electromagnetic induction (3).

† Observations of 1915, method of 1914 (3).

‡ Observations of 1923, magnetometer method (7), error about 2%.

**Rotation by Magnetization** (Einstein and de Haas (40); cf. (9, 30, 39, 96, 105, 108, 109)).—This is the converse of the Barnett effect. A ferromagnetic rod is given an angular momentum about its axis by altering a magnetic field, parallel to the axis, impressed on the rod by means of a solenoid which may be either fixed to the earth or wound rigidly on the rod. The measurements permit the calculation of the ratio  $j/[\mu]$  on the basis of the classical theory and the assumption that the momentum acquired by the rigid system which includes the rod is equal and opposite to the momentum given to the magnetons. For the results of the most reliable experiments, see Table 4.

TABLE 4.—ROTATION BY MAGNETIZATION

The value of  $(j/[\mu])/R_0$  to be expected on the classical theory is unity for a Bohr magneton, and 0.5 for a spinning electron with surface charge.

Material	$(j/[\mu])/R_0$	Method*
Iron.....	0.50+	Bal (30)
	0.53	ACD (9)
	0.50+	ACN (109)
	0.52	ACNR (6)
Nickel.....	0.50+	Bal (30)
	0.57	ACD (9)
	0.50	ACN (109)
Cobalt.....	0.5	ACN (108)
Permalloy.....	0.52+	ACNR (6)
Magnetite.....	0.5	ACN (108)
Heusler alloy.....	0.50	ACN (109)

\* Bal = ballistic; ACD = alternating current, deflection; ACN = alternating current, null; ACNR = alternating current, null, solenoid wound on rod; ACNR = both ACN and ACNR. Excepting ACNR, solenoid is fixed to earth. Data from (6) are preliminary.

Magnetism and Structure; *v. also* (108, 109)

**Effect of Number of Electrons** (*v. also* (19, 61, 62)).—(a) **Pascal's Relation**.—Pascal (82) found that for homologous elements in the 3 families of metalloids,  $\chi_a (=A\chi) = -Ce^{\alpha A}$ , where  $C$  and  $\alpha$  are experimental constants; later (85) he found the relation to apply to nearly all the other diamagnetic elements; see Fig. 1.

(b) **Kossel's Relation** (16, 64, 104).—For atoms and ions having 18 to 29 electrons external to the nucleus, Kossel observed that the magnetic moment depends primarily upon the number of electrons external to the nucleus; *e.g.*, A,  $K^+$ , and  $Ca^{++}$  have 18 such electrons each, and their moments are essentially identical (Fig. 2); removing 2 electrons from the neutral Ca atom ( $Z = 20$ ) changes its moment to that of A ( $Z = 18$ ). This illustrates Kossel's "displacement law." Meyer found the same relation for atoms and ions having 57 to 71 extranuclear electrons (Fig. 3).

**Effect of Distribution of Electrons and Electron Orbits**.—(a) **Langevin's Theory**.—On Langevin's (65) electron theory of magnetism, an ion, atom, or molecule with a completely symmetrical arrangement of electron orbits should be diamagnetic, as exemplified by the rare gases and  $Cu^+$ ,  $Ag^+$ ,  $Au^+$ ; while an unsymmetrical arrangement should produce paramagnetism, as exemplified by Na, K, Ag, Cu, etc.

(b) **Kossel's and Sidgwick's Theory**.—On the theory of Kossel (64) and Sidgwick (102) the electropositive atoms of a saturated compound have lost all the electrons they will part with readily, and the electronegative atoms have taken up all they will take up, and in practically all cases the resulting orbital arrangement is symmetrical, and the compounds are diamagnetic. In a few cases, as in cupric compounds, the arrangement is not symmetrical, and the compound may be paramagnetic. Similarly, unsaturated compounds of diamagnetic elementary substances may be either diamagnetic like oxides of bivalent Pb and Sn, or paramagnetic like NO; *v. also* (10).

(c) **Lewis's Theory**.—On the magnetochemical theory of G. N. Lewis (69), those electrons in a molecule which are paired with one another produce a diamagnetic effect, while an unpaired electron gives a magnetic moment to the molecule, thus producing paramagnetism. In the case of solids and liquids the exact molecular state is in general unknown; but in the case of gases and dilute solutions it can be predicted that every substance with an odd number of electrons in the molecule will be paramagnetic, as exemplified by the following (111): The two odd molecules NO and  $NO_2$  are paramagnetic, while the nitrogen oxides with even molecules are diamagnetic;  $ClO_2$ , which is odd, is paramagnetic even in dilute solution in  $CCl_4$ ; the odd compound  $\alpha$ -naphthyl-diphenylmethyl in benzene solution is paramagnetic (the first case of paramagnetism in an organic compound); for additional data, see (111, 133).

(d) **Welo and Baudisch's Theory**.—On the theory of Welo and Baudisch (127, 128); cf. (10), the diamagnetism of certain salts of magnetic elements is due to the fact that the atoms of the magnetic element have, by sharing with, and transfer from, neighboring atoms, gained a sufficient number of electrons to attain the symmetrical electron configuration of a rare gas. Thus  $K_4Fe(CN)_6$  is diamagnetic because each K atom contributes one electron to the Fe atom by transfer, and each CN group contributes one by sharing. Thus the Fe atom, originally possessing 26 non-nuclear electrons, gains 10 more, and assumes the structure of Kr with 36 electrons.

**Effect of Crystal Structure**.—Though numerous experiments, including the recent ones of Ingersoll and de Vinney on magnetic and non-magnetic Ni films (55); cf. (80), indicate clearly that ferromagnetism occurs only in crystalline masses, the type of crystal appears to have little significance (52, 129, 130). Thus  $\alpha$ -,  $\beta$ - and  $\delta$ -iron are all body-centered cubic, while  $\gamma$ -iron is face-centered cubic. At ordinary temperatures, Ni is face-centered cubic; Co



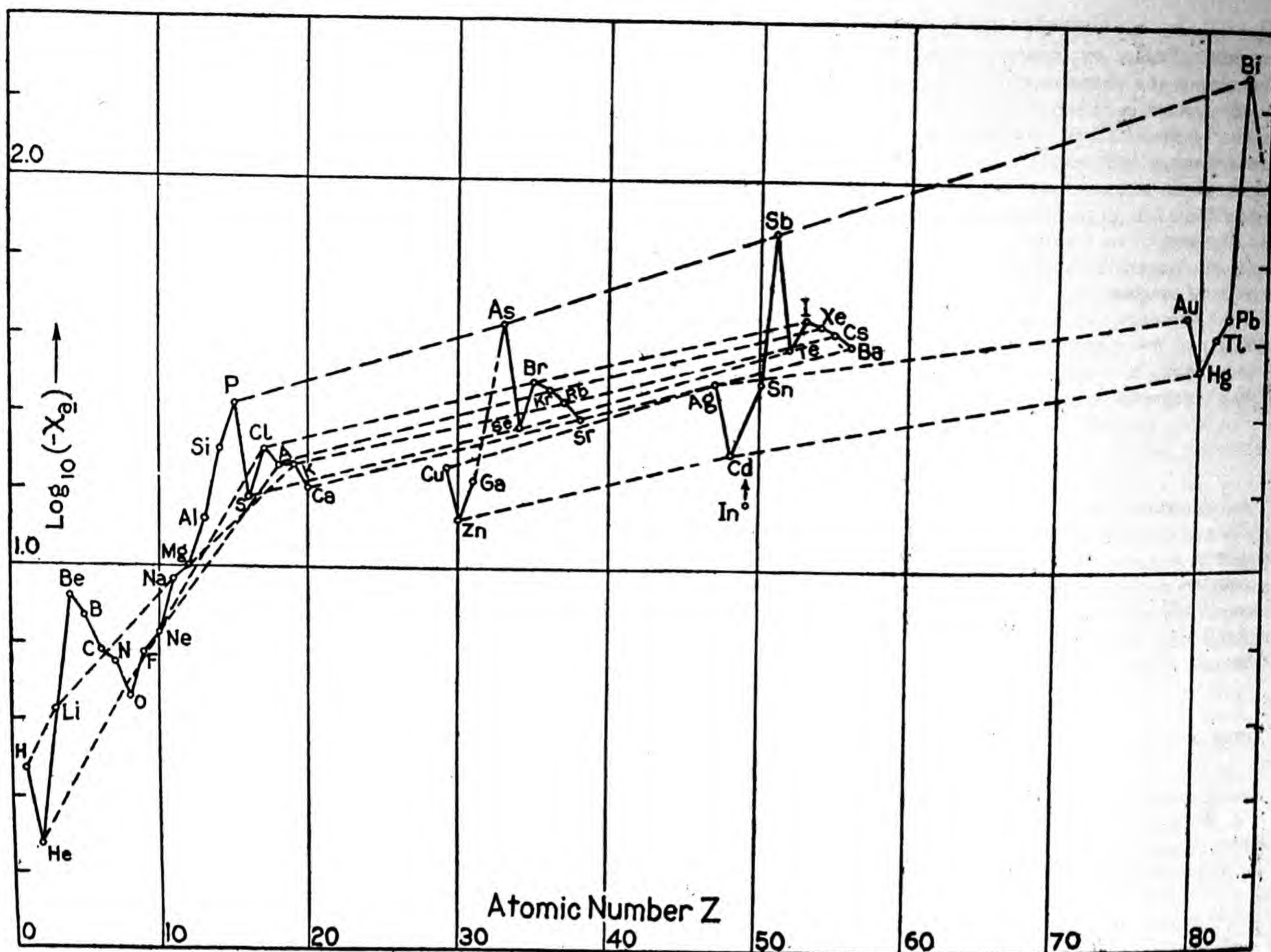


FIG. 1.—Relation between atomic susceptibility ( $\chi_a$ ) of diamagnetic elements and atomic number ( $Z$ ) (Pascal's relation with  $A$  replaced by  $Z$ ). Data for rare gases (<sup>49</sup>, <sup>124</sup>); cf. (<sup>10</sup>), others from Pascal; calculations and interpolations (<sup>12</sup>, <sup>13</sup>, <sup>22</sup>). Dashed (---) lines connect homologous elements and, for  $Z > 14$ , are nearly straight, as demanded by Pascal's relation (p. 347).

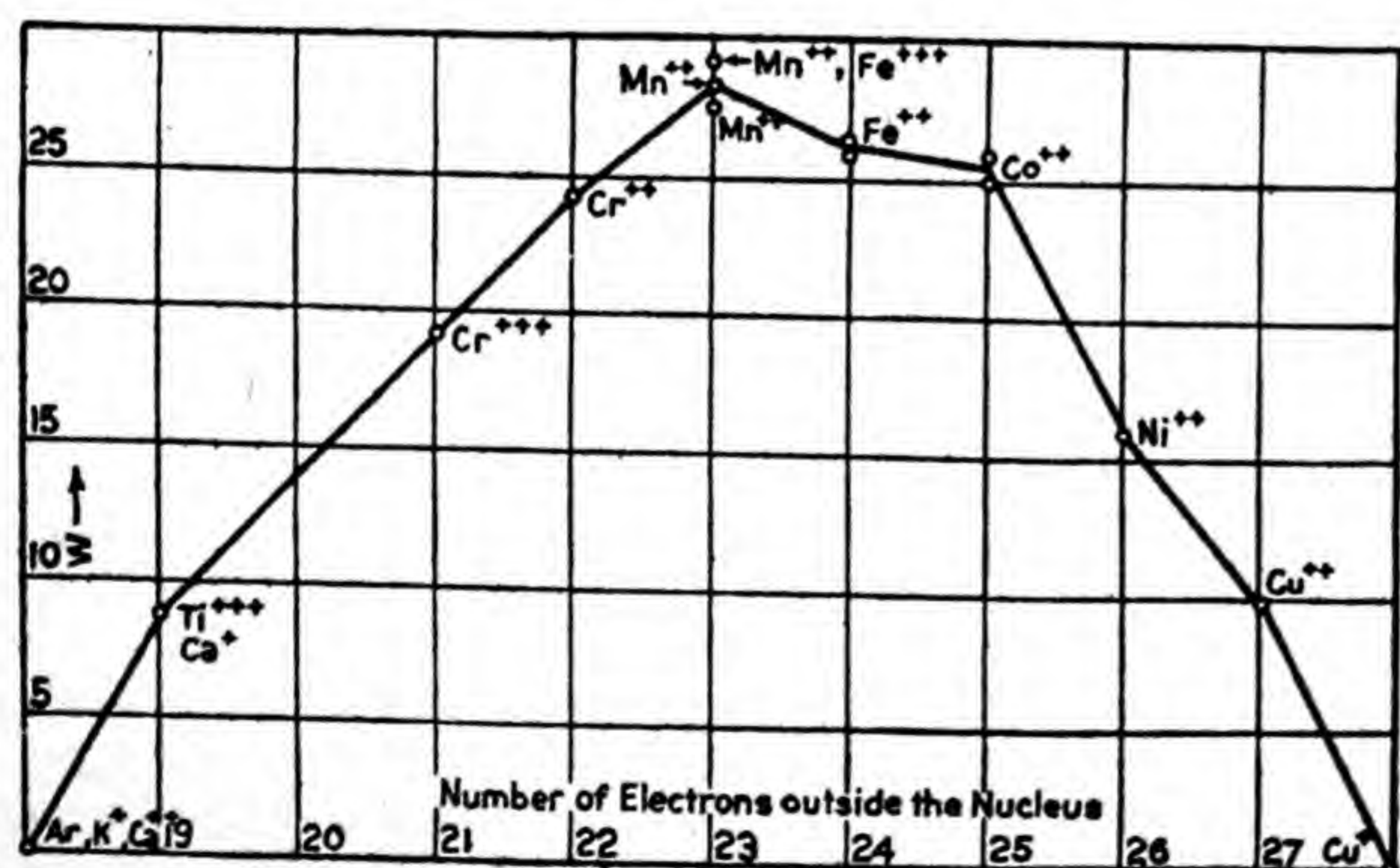


FIG. 2.

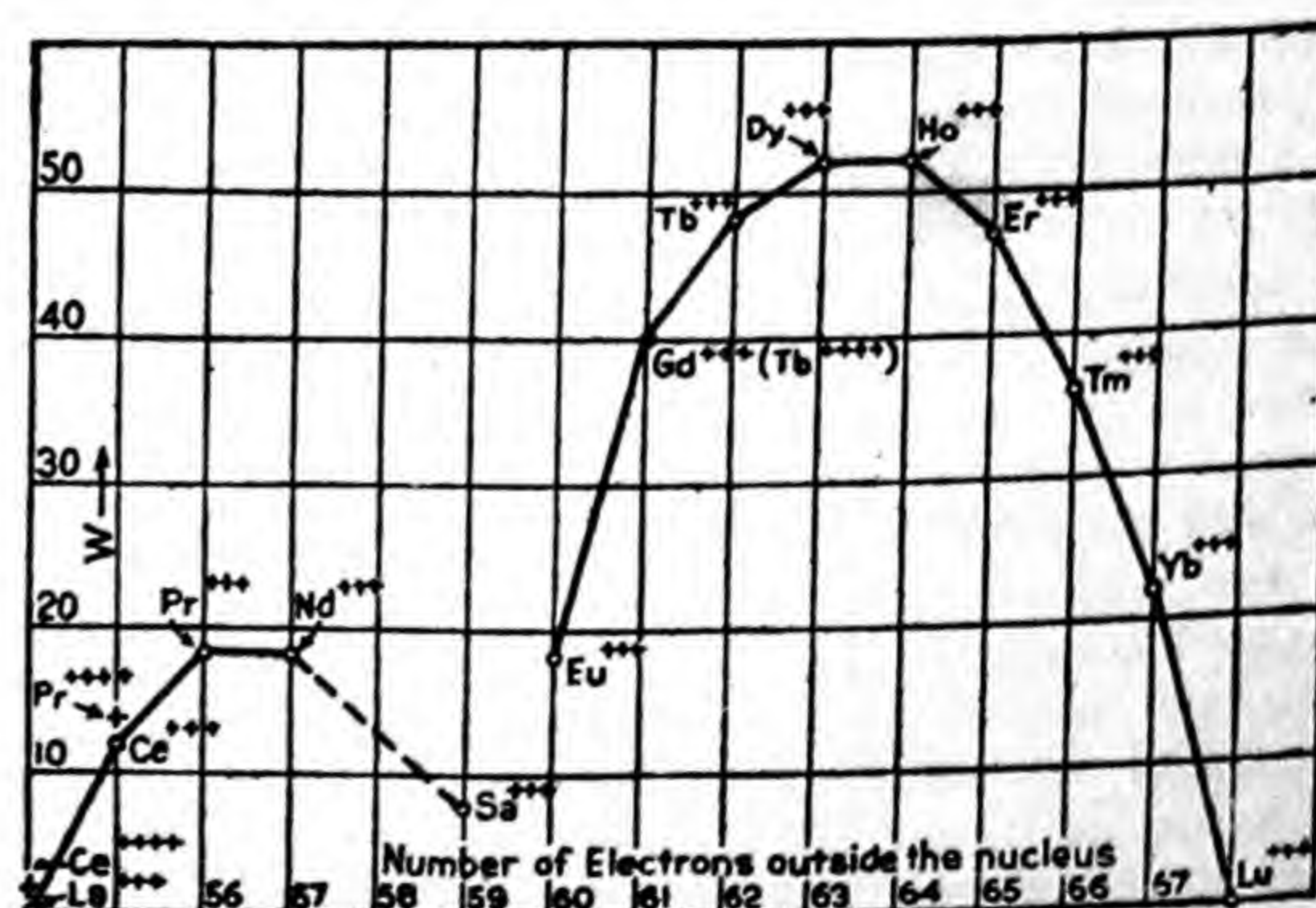


FIG. 3.

FIGS. 2, 3.—Relation between magnetic moment ( $\mu$ ) of atom or ion and the number ( $N$ ) of electrons external to the nucleus (Kossel's relation).  $[\mu] = W[\mu_0]W$ , i.e.,  $W$  = number of Weiss magnetons per atom or ion. In Fig. 2, data from (<sup>104</sup>); in Fig. 3, ° from (<sup>10</sup>), + from (<sup>74</sup>) computations assume the Langevin-Weiss theory (p. 350).



is hexagonal or face-centered cubic; pyrrhotite ( $\text{Fe}_7\text{S}_8$ ), hexagonal; magnetite ( $\text{Fe}_3\text{O}_4$ ), cubic; and hematite ( $\text{Fe}_2\text{O}_3$ ), rhombohedral. Thermomagnetic changes in Heusler alloy are not accompanied by any change in the X-ray diffraction pattern (<sup>139</sup>), and the pattern of Fe-Ni alloys does not change when the composition passes through that of the extremely permeable permalloy (<sup>2</sup>). Paramagnetic and diamagnetic solids have a great variety of crystal forms, though in certain groups homologous elements have the same crystal structure (<sup>10</sup>). Magnetization may produce no change in the crystal structure (<sup>138</sup>); e.g., Laue photographs of crystals of magnetite and of hematite are unchanged by a field of 1000 gauss (<sup>34</sup>), and those of Heusler alloy are unchanged by 3500 gauss (<sup>139</sup>), and the X-ray spectra obtained by reflection from a crystal of magnetite are not affected in any way by subjecting the crystal to a strong magnetic field (<sup>33</sup>); cf. (<sup>138</sup>).

### Additivity Relations

**Simple Additivity.**—The law of additivity may be written  $m\chi = \sum m_i\chi_i$ , where  $m_i$  is the mass of a constituent  $i$  of a compound or mixture ( $M$ ) of mass  $m = \sum m_i$ , and  $\chi$  and  $\chi_i$  are the specific susceptibilities of  $M$  and the constituent  $i$ . The summation ( $\sum$ ) is extended to all constituents. For many compounds and mixtures, this law appears to be valid; for many others, the departures from it are great.

TABLE 5.—ADDITIVITY RELATION AS APPLIED TO SOLID PARAMAGNETIC HYDRATES (<sup>43</sup>)

Some data satisfy the relation  $m\chi = \sum m_i\chi_i$ , and some do not.  $\chi_o$  = observed specific susceptibility;  $\chi_c$  = specific susceptibility calculated from data in last column by subtracting the (negative) susceptibility of the  $\text{H}_2\text{O}$  lost. Error  $\leq 1\%$ ; unit of  $\chi = 10^{-6}$  cgs unit.

$\text{H}_2\text{O}$ .....	None		1 $\text{H}_2\text{O}$		$n\text{H}_2\text{O}$	
Salt	$\chi_o$	$\chi_c$	$\chi_o$	$\chi_c$	$n$	$\chi_o$
$\text{CuSO}_4$ .....	8.6	9.6	8.6	8.6	5	5.9
$\text{NiSO}_4$ .....	25.5	27.8	24.1	23.8	6	15.6
$\text{CoSO}_4$ .....	60.8	60.0	53.6	53.2	7	3.5
$\text{Sm}_2(\text{SO}_4)_3$ .....	3.43	3.39			8	2.6
$\text{Gd}_2(\text{SO}_4)_3$ .....	92.6	92.7			8	74.7

As applied to solutions, the law of additivity requires that the molecular susceptibility of the solute be independent of the concentration; this is known as *Wiedemann's law*. In many cases of apparent failure of Wiedemann's law, it is probable that more than one type of each of certain constituents is present and that the relative amounts of these types change with the concentration. Hydrolysis furnishes an illustration of such changes. When a salt is hydrolyzed in a solution, the value of  $\chi$  for the ion, as deduced from that for the solution on the assumption that the simple additivity relation holds, commonly differs from that deduced from observations taken under other conditions. In such cases, progressive reduction of hydrolysis by addition of acid enables one to extrapolate to the condition of no hydrolysis; this extrapolated value for the ion frequently agrees with that found under other conditions of no hydrolysis (<sup>15</sup>, <sup>23</sup>, <sup>41</sup>, <sup>94</sup>).

As applied to molecules, the additivity relation requires that the molecular susceptibility  $\chi_m (= M\chi)$  shall be computable from the atomic (ionic) susceptibilities of the constituent atoms (ions). Pascal so applied it, and found that consistent results could be obtained in many cases, especially of saturated organic compounds. Weiss similarly applied the relation in determining the ionic susceptibilities of metals, from the observed susceptibilities of salts and solutions; v. (<sup>118</sup>).

TABLE 6.—ATOMIC AND ATOMIC-GROUP SUSCEPTIBILITIES (<sup>82</sup>, <sup>83</sup>, <sup>84</sup>)

The values given below are in general use in determining ionic susceptibilities of metals, and assume that  $m\chi$  for  $\text{H}_2\text{O}$  is  $13.0 \times 10^{-6}$ .  $m\chi$  = atomic or atomic-group susceptibility; in the former case,  $m$  = atomic weight; in the latter,  $m$  = formula weight of the group; unit of  $m\chi = 10^{-6}$ .

Atom.....	Br	C	Cl	F	H	Hg	I	K	Na	O
$-m\chi$ .....	30.6	6.0	20.1	6.3	2.93	33.4	44.6	18.5	9.2	4.6
Atom or atom group	P	S	Se	Te	$\text{H}_2\text{O}$	$\text{SO}_4$	$\text{NO}_3$	$\text{NH}_3$	CN	
$-m\chi$ .....	26.3	15.0	23.1	37.5	13.0	33.6	14.2	14.4	10.8	

**Pascal's Relation** (<sup>82</sup>, <sup>83</sup>).—In those cases in which the application to molecules of the simple additivity relation led to inconsistent results, Pascal employed the more general equation  $M\chi = \sum n_i A_i \chi_i + \lambda$ , or its equivalent  $\chi_m = \sum n_i \chi_i A_i + \lambda$ , in which  $n_i$  is the number of atoms of species  $i$  and atomic weight  $A_i$  that are contained in a molecule of molecular weight  $M$ , and  $\lambda$  measures the deviation from the law of additivity;  $\lambda$  depends upon the nature of the molecule. Frequently,  $\lambda$  has the same value for all those organic compounds which are of similar type. Thus, if unit of  $\chi$  is  $10^{-7}$ ,

$$(m\chi)_{(\text{C}_6\text{H}_5\text{Cl})} - (m\chi)_{(\text{C}_6\text{H}_5\text{Br})} = 103$$

and

$$(m\chi)_{(\text{CH}_3\text{ClCO}_2\text{C}_2\text{H}_5)} - (m\chi)_{(\text{CH}_3\text{BrCO}_2\text{C}_2\text{H}_5)} = 107$$

while

$$(m\chi)_{\text{Cl}} - (m\chi)_{\text{Br}} = 105;$$

also

$$(m\chi)_{(\text{C}_6\text{H}_5\text{Br})} - (m\chi)_{(\text{C}_6\text{H}_5\text{I})} = 138$$

and

$$(m\chi)_{(\text{CH}_3\text{BrCO}_2\text{C}_2\text{H}_5)} - (m\chi)_{(\text{CH}_3\text{ICO}_2\text{C}_2\text{H}_5)} = 148$$

while

$$(m\chi)_{\text{Br}} - (m\chi)_{\text{I}} = 140;$$

the differences for the compounds are uncertain by 8 or 10 units. For values of  $\lambda$ , see Table 7.

TABLE 7.—PASCAL'S  $\lambda$  FOR CERTAIN BONDS IN ORGANIC COMPOUNDS

$M\chi = \sum n_i A_i \chi_i + \lambda$ . For the saturated  $\text{C}_n\text{H}_{2n+2}$  compounds,  $\lambda = 0$ ; unit of  $\chi = 10^{-6}$  cgs unit

Bond	$\lambda$	Bond	$\lambda$
Benzene bond.....	-1.5	Polyethylene bond.....	+10.6
Naphthalene bond.....	-6.1	$\text{C} = \text{O}$ .....	+ 8.2
Hexamethylene bond....	+3.0	$\text{C} \equiv \text{N}$ .....	+ 0.8
Ethylene bond.....	+5.5	$\text{C} \equiv \text{N}$ .....	0

TABLE 8.—EFFECTIVE ATOMIC SUSCEPTIBILITY  $(\chi_a)_o$  OF O IN ORGANIC COMPOUNDS

Assumes  $\lambda = 0$ ; unit of  $(\chi_a)_o = 10^{-6}$  cgs unit

Type of bond	$(\chi_a)_o$
Singly bound to any two atoms, $-\text{O}-$ .....	-4.6
Doubly bound to a single C not carrying another O....	+1.7
Doubly bound to a single C carrying a second O.....	-3.4
Doubly bound to any single polyvalent atom: $(\alpha\chi_o)$ is of the same sign as for the corresponding case in which the C is the polyvalent atom.	

### Theories of Diamagnetism

**The Weber-Langevin Theory** (<sup>65</sup>, <sup>116</sup>).—On this theory the magnetic moment of a diamagnetic atom in a neutral region is zero because the electron orbits are such and so arranged that the vector sum of their individual moments is zero. The orbits are assumed to be rigid, independent of  $T$ , and in general unaffected by chemical and physical changes; but the velocities of the electrons in the orbits are changed by the application of a magnetic field. On this last the existence of diamagnetism depends. On this theory, for an isotropic substance, or for atoms oriented at random,  $\chi_o =$



$-(e^2 N_0 / 12 \pi m_0) \sum n_i a_i$ ;  $a_i$  = area of an orbit of type  $i$ ;  $n_i$  = number of such orbits per atom. Variations in  $\chi_a$  may result from a paramagnetic relative displacement of the orbits, from distortion, due to a molecular electric or magnetic field, when a change of state occurs (69, 81, 82, 83) (Oxley (81) attributes to such fields intensities of the order of  $10^7$  gauss, cf. *infra*), and in the case of conductors, possibly but not certainly (67), from the presence of free electrons (99, 135).

TABLE 9.—EFFECT OF LIQUEFACTION OF DIAMAGNETIC SOLIDS: ILLUSTRATIVE (81)

If  $\delta\chi/\chi$  is positive, the liquid is more diamagnetic than the solid; unit of  $\delta\chi/\chi = 1\%$

Substance		$\delta\chi/\chi$	Lit.
H <sub>2</sub> O	Water.....	3+	(56)
Hg	Mercury.....	14	(81)
C <sub>6</sub> H <sub>6</sub>	Benzene.....	0	(81)
C <sub>6</sub> H <sub>7</sub> N	Aniline.....	5	(81)
C <sub>7</sub> H <sub>5</sub> ClO	Benzoyl chloride.....	-5	(81)
C <sub>7</sub> H <sub>8</sub>	Toluene.....	5	(81)
C <sub>8</sub> H <sub>10</sub>	<i>o</i> -Xylene.....	5	(81)

**Pauli's Theory.**—On this theory (4, 86) which is applicable only to monatomic gases, diamagnetism is due to a rotation of the complete atom (Larmor rotation) produced by the magnetic field. For random orientation,  $\chi_a$  is just twice as great as on the Weber-Langevin theory, i.e.,  $\chi_a = -(e^2 N_0 / 6 \pi m_0) \sum n_i a_i$ .

#### Atomic Radii

From measurements of the susceptibility of a diamagnetic substance it is possible, on the basis of either of these theories, to compute the mean of the areas of the several electronic orbits in the atom and the radius ( $r$ ) of this mean area, assumed to be circular. The value obtained for  $r$  depends upon the theory applied. By the use of Bohr's theory of the atom, it is possible, in certain cases, to derive from  $r$  the radius ( $r_m$ ) of the outermost orbit (19, 82). The effective atomic radius can also be obtained from viscosity and other data. For numerical values of the several  $r$ 's, see Table 10.

TABLE 10.—ATOMIC RADII

The radii are derived as follows:

- $r_w$  [ $r_p$ ] From mean area of the electronic orbits as given by the Weber-Langevin [the Pauli] theory (15, 19);  $r_w = r_p \sqrt{2}$ .
- $r_m$  Mean radius of outer shell of electrons, as computed by Cabrera (19) from observations of Wills and Hector (49, 134); where 2 values are given (ions of A structure) they are based on slightly different assumptions.
- $r_v$  From measurements of viscosity; computed by Jeans (60).
- $r_c$  From crystal data by method of Fajans and Herzfeld (42); computed by Grimm (48).
- $r_l$  From Landé's atomic model, cubical symmetry; computed by Schwendenwein (100).
- $r_b$  Radius of combination, Bragg (12).

Unit of  $r = 1 \mu\mu = 10^{-6} \mu = 10^{-10}$  cm

(1)	$r_w$	$r_p$	$r_m$	$r_v$	$r_c$	$r_l$	$r_b$
A.....	85	60	85	181	87	109	105
Ca <sup>++</sup> .....			69, 74		67		170
Cl.....	92	65		168			
Cl <sup>-</sup> .....			98, 92		95		105
F <sup>-</sup> .....			55		75		
H.....	146	103		177			
He.....	81	57	57	111			
Hg.....	55	39		105			
K.....	84	59		159			
K <sup>+</sup> .....			76, 80		79		207
Kr.....			103	205	97	112	
Mg <sup>++</sup> .....			39		39		

TABLE 10.—(Continued)

(1)	$r_w$	$r_p$	$r_m$	$r_v$	$r_c$	$r_l$	$r_b$
N.....	76	54		146			
N <sup>---</sup> .....			77				
Na <sup>+</sup> .....			43		52		
Ne.....	68	48	54	111	63	74	
O.....	65	46		146			
O <sup>---</sup> .....			65		89		
P <sup>---</sup> .....			137, 111				
S <sup>---</sup> .....			113, 101		109		102
Xe.....			144	242	110	126	

#### Theories of Paramagnetism

$\chi$  is Independent of the Temperature.—No detailed theory has been developed; see, however, (124).

$\chi$  Varies with the Temperature.—(a) Langevin's Theory.—Langevin has developed a fundamental theory for gases, and on this many other theories have been based (see *infra* and p. 352). His theory leads to the relation  $\sigma_a/\sigma_{\infty} (= \sigma/\sigma_{\infty}) = \coth a - 1/a$ , where  $a \equiv \sigma_{\infty} H / RT$ . If  $a$  is small, the relation becomes  $\sigma_a/H (= \chi_a) = (\sigma_{\infty})^2 / 3RT = C_a/T$ ; or, divided by  $A$ ,  $\chi = C/T$ , which is Curie's law (36). Curie's law is valid for O<sub>2</sub> both at high temperatures and (83), if density corresponds to a pressure of 100 atm. at 290°K, within the ranges 170 to 290°K and 10 to 18 kilogauss,  $C$  being  $(302.8 \pm 1.5) \times 10^{-4}$ ; it is also valid for certain solids and solutions of salts, see *infra* and Tables 11, 12, 14.

Proceeding on quite different assumptions, Weiss has shown that in certain cases Langevin's relation may be valid for solid bodies (119), and it has been established experimentally (Onnes, Oosterhuis, Woltjer) (75, 136) for solid gadolinium sulfate, Gd<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·8H<sub>2</sub>O, over the ranges 1.3 to 300°K and 3.3 to 22 kilogauss;  $a$  was varied from a small value to 7.0; Curie's law applies if  $a < 0.7$ .

(b) Weiss's Generalization of Langevin's Theory.—Weiss and Onnes independently observed that many series of data for which Curie's law fails satisfy the more general relation  $\chi(T - \Theta) = C$  (Weiss's law), and Weiss has shown that Langevin's theory leads to this expression when the orientations of the elementary moments are modified by intense molecular fields;  $C_a = (\sigma_{\infty})^2 / 3R$ , as in Langevin's theory when  $a$  is small. The intensities of the molecular fields necessary to account for the observed values of  $\Theta$  exceed  $10^6$  gauss if assumed to be magnetic; some of the values, as estimated by Weiss (122), are, in this unit: Fe, 6.5; Ni, 6.4; Co, 8.9; magnetite, 14.3.

If the elementary magnetic moments were each accompanied by an electric moment having the same axis, the resultant molecular electrical field would produce the same effect as the molecular magnetic field at first assumed by Weiss (121). The required elementary electric moment is  $e = 1.5 \sqrt{RM\Theta/\pi d N_0}$ , electrostatic units, where  $d$  = density of the substance, and other symbols have same significance as elsewhere. Thus if the unit of  $e$  is  $10^{-18}$  cgse unit, the values of  $e$  for Fe, Co, and Ni are, respectively, 1.09, 1.25, and 0.85, if the atom is the basal element; if the basal element for Fe is 3 atoms and for magnetite is 0.5Fe<sub>3</sub>O<sub>4</sub>, the corresponding values of  $e$  are 1.90 for Fe and 1.74 for Fe<sub>3</sub>O<sub>4</sub>. All these values are very close to those (0.34 to 1.18) obtained by Debye (37, 73) for the moments of dipoles in insulators. The value given for Ni is much the most reliable.

An explanation of the existence of  $\Theta$  in mixtures of oxygen and nitrogen (cf. Table 14) has been given in terms of polymerization (70, 89).

For solutions, experiments of Foëx (44) and of Cabrera and Duperier (21) have shown that in general  $\Theta$  is not zero; and the results of the latter indicate that  $\Theta$  is independent of the concentration and of the nature of the anion.

For substances which are ferromagnetic at ordinary temperatures, Weiss's theory interprets  $\Theta$  as the temperature at which the



substance becomes paramagnetic (Curie point, critical temperature). For pure Fe-Ni alloys ranging from Fe<sub>2</sub>Ni (34.4% Ni) to 100% Ni, Weiss's law is followed exactly from temperatures near the Curie point to ca. 1200°C, and  $\Theta$  is found<sup>(91)</sup> to be a little higher than the Curie point. From many series of observations at Zürich<sup>(120)</sup>, the atomic magnetic moment  $[\mu]$  for pure Ni above the Curie point, calculated on the basis of the Langevin-Weiss theory, has been found to be  $[\mu] = (8.02 \pm 0.02) [\mu_0]_w$ ; cf. p. 346.

For other ferromagnetic substances at temperatures above the Curie point, Weiss's law is not certainly followed even over moderate ranges of  $T$ .

For most paramagnetic substances, it holds over a considerable range of  $T$ , but, in general, fails at very low temperatures. This failure constitutes the *cryomagnetic anomaly* of Onnes. For ions both of the iron group and of the rare earth groups, Cabrera<sup>(20)</sup> has shown that  $\Theta$  in general decreases with increase of ionic magnetic moment, the relation for ions of a given class being linear.

TABLE 11.—WEISS'S LAW AS APPLIED TO PARAMAGNETIC SOLIDS: VALUES OF  $\Theta$  AND RANGES OF VALIDITY; ILLUSTRATIVE

Weiss's law,  $\chi(T - \Theta) = C$ , usually fails at very low temperatures. Range of  $T$  = range over which the law holds good;  $T'$  = temperature below the range;  $a, m, s$  indicate whether  $\chi$  and  $C$  refer to the atomic (metal atom), molecular, or specific magnetization. Error in  $\Theta$  ranges ca. from  $<1$  to  $2^\circ\text{K}$ ; unit of  $\chi = 1 \text{ cgs m}$ ; of  $T, T'$ , and  $\Theta = 1^\circ\text{K}$ .

Substance	(2)	Range of $T$	$\Theta$	$C$	$\chi(T' - \Theta)$	$T'$	Lit.
Gd(C <sub>2</sub> H <sub>3</sub> SO <sub>4</sub> ) <sub>3</sub> ·9H <sub>2</sub> O.....	$a^*$	14.6–291.5	0	7.05			(58)
CoSO <sub>4</sub> .....	$m$	77.3–289.5	– 45	3.22	4.27	14.8	(57)
NiSO <sub>4</sub> ·7H <sub>2</sub> O.....	$m^*$	169.6–292.2	+ 59	1.077	3.76	14.6	(57)
Pt†.....	$s$	325–685	–1124	0.001663	0.001651	289	(44)
Pd†.....	$s$	479–722	– 226	0.003043	0.002997	290	(44)
Fe <sub>2</sub> (NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>4</sub> ·24H <sub>2</sub> O.....	$m$	14.7–290		8.50			(78)
Dy <sub>2</sub> O <sub>3</sub> .....	$m$	13.9–288.5	– 18	27.6			(76)

\* Values have been corrected for diamagnetism of the anion and of the water of crystallization.

† Values have been corrected for diamagnetism of the metal atom.

TABLE 12.—WEISS'S LAW AS APPLIED TO PARAMAGNETIC SOLIDS: VARIATION OF  $\Theta$  WITH MOLECULAR CONSTITUTION

$\chi(T - \Theta) = C$ ; mean error in  $\Theta = 2^\circ$ , maximum error =  $7^\circ\text{K}$ ; unit of  $\Theta = 1^\circ\text{K}$

Cation	Ni <sup>++</sup>		Co <sup>++</sup>		Fe <sup>++</sup>		Fe <sup>+++</sup>	
	$\Theta$	Lit.	$\Theta$	Lit.	$\Theta$	Lit.	$\Theta$	Lit.
SO <sub>4</sub> .....	–79	(57)	–45	(57)	–12	(14)†	–66	(14)†
			–30‡	(112)	–31	(57)		
			–19§	(57)				
SO <sub>4</sub> ·7H <sub>2</sub> O.....	+59	(57)	–48	(101)				
(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> .....			–14	(57)	– 1	(57)	–12	(14)†
(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O.....	– 4	(57)	–22	(57)	+ 3	(57)	0	(78)
Cl <sub>3</sub> .....	+78‡	(112)	+47	(112)	+30	(14)†	– 3	(14)†
	+38§	(112)	+34	(14)†				

\* For Fe<sup>+++</sup> the salts are Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, Fe<sub>2</sub>(NH<sub>4</sub>)<sub>2</sub>(SO<sub>4</sub>)<sub>4</sub>, Fe<sub>2</sub>(NH<sub>4</sub>)<sub>2</sub>(SO<sub>4</sub>)<sub>4</sub>·24H<sub>2</sub>O, and FeCl<sub>3</sub>.

† Computed from the data of (51, 56).

‡ At lower temperatures.

§ At higher temperatures.

TABLE 13.—WEISS'S LAW AS APPLIED TO SOLUTIONS AND A PURE LIQUID: VALUES OF  $\Theta$  AND RANGES OF VALIDITY

$\chi(T - \Theta) = C$ ; errors in  $C$  range from 0.1% to 0.2%. Discrepancies in  $\Theta$  for a given ion are probably accidental. Solvent is H<sub>2</sub>O unless another is indicated. Conc. = concentration, grams of solute per 100 g of solution, except where otherwise indicated; unit of  $\Theta = 1^\circ\text{K}$ ;  $T$  = absolute temperature,  $^\circ\text{K}$ .

TABLE 13.—(Continued)

Solute	Conc.	Range of $T$	$\Theta$	Lit.
MnCl <sub>2</sub> .....	3.0	293–373	–28	(21)
	15.0	293–376	–25	(21)
	37.9	293–371	–24	(21)
Mn(NO <sub>3</sub> ) <sub>2</sub> .....	6.4	293–373	–23	(21)
	36.9	293–372	–27	(21)
FeCl <sub>3</sub> *.....	0.148	290–400	–11	(44)
	0.148	290–400	+ 2	(44)
	0.161	290–400	+ 1	(44)
	0.183	290–400	– 4	(44)
Fe(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O†.....	0.0315	290–373	0	(44)
	0.0405	291–384	– 1	(44)
CoCl <sub>2</sub> .....	7.9	283–413	–11.6	(29)
	14.8	283–413	–12.1	(29)
CoSO <sub>4</sub> .....	4.1	283–413	–11.2	(29)
	9.8	283–413	–12	(29)
Co(NO <sub>3</sub> ) <sub>2</sub> .....	9.4	283–413	–12.4	(29)
	0.076*	290–400	– 2	(44)
	0.139*	290–400	– 3	(44)
	0.139*	290–400	–17	(44)
NiCl <sub>2</sub> .....	4.6'	279–363	0	(123)
	4.6‡	292–329	0	(123)
	Satd.§	290–400	0	(44)
Ni(NO <sub>3</sub> ) <sub>2</sub> .....	12.4	293–370	– 4.2	(21)
	44.4	293–375	– 1.4	(21)
V <sub>2</sub> O <sub>2</sub> Cl <sub>4</sub> ·5H <sub>2</sub> O  .....	100	194–326	–29	(88)
	100	194–326	–45	(88)

\* Conc. = grams of metal per 100 g solution; limits of  $T$  only approximate.

† Conc. = grams of Fe per 100 g solution; solvent is mixture of H<sub>2</sub>O and H<sub>2</sub>SO<sub>4</sub>.

‡ Solvent is H<sub>2</sub>O + 6.8% NH<sub>3</sub>.

§ Solution is saturated, concentration  $\geq 20\%$  Ni; limits of  $T$  only approximate.

|| A viscous liquid.

TABLE 14.—WEISS'S LAW AS APPLIED TO MIXTURE OF O<sub>2</sub> AND N<sub>2</sub> (89)

$V_0$  = volume of O<sub>2</sub> contained in volume  $V$  at the same temperature and pressure.  $\chi(T - \Theta) = C$ . Mean error in  $\Theta$  ca.  $0.2^\circ$ ; unit of  $\Theta = 1^\circ\text{K}$ ; of  $\chi = 10^{-4} \text{ cgs m unit}$ .

$V_0/V$ .....	1 (8)	$\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{5}$	Mean $C$
$C$ .....	315.8	315.3	314.7	315	315.3	315	315.2
$\Theta$ .....		–29.5	–16.5	–9.5	–4.5	–2.2	

TABLE 15.—MAGNETIC MOMENTS  $[\mu]$  OF MOLECULES AND IONS OF PARAMAGNETIC SUBSTANCES

I. Molecules. Only O<sub>2</sub> and NO. Computation based on Langevin's theory (p. 350) and assumption of a single fixed moment.

II. Ions. Except where otherwise stated: For solutions, solvent is H<sub>2</sub>O, Wiedemann's law is valid, and Curie's law is assumed without having been established. For solid salts, Weiss's law is valid within the "range" indicated. Computation is based on the Langevin-Weiss theory (p. 350).

In column (1) is named the ion or molecule considered and in (2), the molecule from which it is derived. The pure substance is a solid salt unless the contrary is indicated by  $g$  = gas, or  $l$  = liquid;  $[\mu]$  refers to the gram-ion (-molecule) or to the individual ion (molecule) according as  $[\mu]_w = [\mu_0]_w$  or  $[\mu_0]_w$ .  $[\mu]_l = W[\mu]_w$ .  $t$  = centigrade temperature,  $^\circ\text{C}$ .



TABLE 15.—(Continued)

State of substance		Solution		Pure		
(1)	(2)	W	Lit.	Range of $t$	W	Lit.
O <sub>2</sub>	O <sub>2</sub> .....			$g$	14.13	(8, 120)
NO	NO.....			$g$	9.18	(8, 120)
Cu <sup>++</sup>	Various.....	9.5	(24)			
		9.8				
Mn <sup>++</sup>	CuCl <sub>2</sub> .....			+ 20 — +500	10.0	(51, 56, 118)
	CuSO <sub>4</sub> .....			— 120 — +700	9.96	(51, 56, 118)
	MnCl <sub>2</sub> .....	28.05*	(21)	— 180 — +630	27.04	(51, 56, 118)
				+ 15 — +575	28.45	(112)
	MnSO <sub>4</sub> .....			+ 9 — +270	29.04	(112)
Fe <sup>++</sup>				+ 280 — +550	29.04	(112)
	MnSO <sub>4</sub> ·4H <sub>2</sub> O...			— 68.6 — + 28.5	29.04	(44)
	Mn(NO <sub>3</sub> ) <sub>2</sub> .....	28.07*	(21)			
	FeCl <sub>2</sub> .....			— 182 — +200	25.9	(51, 56, 118)
	FeCl <sub>2</sub> ·4H <sub>2</sub> O....			— 180 — + 20	26.0	(51, 56, 118)
Fe <sup>+++</sup>	FeSO <sub>4</sub> .....			— 177 — +660	26.08	(51, 56, 118)
	FeSO <sub>4</sub> ·7H <sub>2</sub> O...	26.51	(125)	— 173 — + 23	26.0	(51, 56, 118)
	Fe(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O...	26.49	(125)	— 73 — + 16	25.97	(44)
	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .....			— 180 — +660	29.00	(51, 56, 118)
				+ 16 — +575	28.95	(112)
Co <sup>++</sup>	Fe <sub>2</sub> (NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> .....			— 180 — +400	29.0	(51, 56, 118)
	CoCl <sub>2</sub> .....	25.06*	(29)	+ 15.5 — +325	24.96	(112)
	CoSO <sub>4</sub> .....	25.03*	(29)	+ 15 — +550	25.00	(112)
				— 196 — + 16	25.2	(57)
	CoSO <sub>4</sub> ↑.....	26.03*	(29)	+ 8 — +422	26.0	(101)
Ni <sup>++</sup>	CoSO <sub>4</sub> ·7H <sub>2</sub> O....			— 209 — + 17	25.04	(57)
	Co(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O...			— 196 — + 17.5	24.75	(57)
	Co(NO <sub>3</sub> ) <sub>2</sub> .....	25.02*	(29, 44)			
		25.54*	(44)			
	NiCl <sub>2</sub> .....	16.02*	(13, 25, 123)	— 120 — +360	16.08	(51, 56, 118)
Cr <sup>++</sup>				+ 15 — +125	16.03	(112)
				+ 150 — +500	16.92	(112)
	NiSO <sub>4</sub> .....	16.06	(25, 123)	— 180 — +120	17	(51, 56, 118)
	Ni(NO <sub>3</sub> ) <sub>2</sub> .....	16.04	(25, 123)	— 196 — + 16	16.9	(57)
		15.96*	(21)			
Cr <sup>+++</sup>	NiCl <sub>2</sub> + NiSO <sub>4</sub> + Ni(NO <sub>3</sub> ) <sub>2</sub> ↑.....	15.58*	(123)			
	CrCl <sub>2</sub> .....	23.72	(27)			
		23.89	(27)			
	CrSO <sub>4</sub> ·7H <sub>2</sub> O...	23.98	(27)			
	Cr <sub>2</sub> O <sub>3</sub> ·7H <sub>2</sub> O....			— 164 — + 19	19.07	(51, 56, 118)
V <sup>+++</sup>	CrCl <sub>2</sub> .....			— 167 — + 18	18.87	(51, 56, 118)
				+ 250 — +550	18.87	(51, 56, 118)
	CrCl <sub>2</sub> ·4H <sub>2</sub> O....	18.72‡	(41)			
	CrCl <sub>2</sub> ·6H <sub>2</sub> O....	18.77‡	(41)			
	Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .....	18.89	(23)			
V <sup>++++</sup>	Cr(NO <sub>3</sub> ) <sub>3</sub>   .....	18.99	(23)			
	V <sub>2</sub> O <sub>5</sub> ·4.5H <sub>2</sub> O‡	**			7.94	(88)
	VOSO <sub>4</sub> ·3H <sub>2</sub> O...	**		— 79 — +100	8.95	(88)

Rare earths; salt of type R<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·8H<sub>2</sub>O, except where noted (18, 18, 74, 131, 132)††

Ion <sup>+++</sup>	La	Ce††	Pr	Nd	Nd§§	Sa
W.....	0	11.89	17.89	18.00	18.05	7.64(?)
±δW.....		1.2	0.3	0.3	1	
δP.....		— 1.1	— 0.6	0.0	+ 0.3	

\* Weiss's law found to be valid, value of  $\Theta$  was found and used in computation.

† Anhydrous salt prepared by calcining CoSO<sub>4</sub>·7H<sub>2</sub>O.

‡ Solvent is H<sub>2</sub>O + xNH<sub>3</sub>.

§ Hydrolysis is very weak and value of  $W$  closely approaches 19.00 as hydrolysis is reduced by addition of HCl.

|| Hydrolysis is very weak.

‡ A viscous liquid.

\*\* Erculisse finds the same moments ( $W = 8$  and  $9$ ) when V<sup>++++</sup> occurs in aqueous solutions (88).

†† As Curie's law has been found to be valid for Gd<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·8H<sub>2</sub>O (see p. 350),  $\Theta$  has been assumed to be 0 for the sulfates.  $\delta W = \%$  uncertainty in  $W$ ;  $\delta P = \%$  departure of  $W$  from nearest integer.

‡‡ Ce<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·5H<sub>2</sub>O.

§§ Oxide.

TABLE 15.—(Continued)

Ion <sup>+++</sup>	Eu	Gd	Tb	Dy	Dy§§	Ho
W.....	17.92	40.07	47.92	52.25	52.00	52.00
±δW.....	0.1	0.2	0.4	0.3	0.3	0.2
δP.....	— 0.4	+ 0.2	— 0.2	+ 0.5	0.0	0.0

Ion <sup>+++</sup>	Er	Er§§	Tm	Yb	Lu
W.....	46.98	47.09	35.85	21.74	0
±δW.....	0.3	1	0.1	0.2	
δP.....	— 0.0	+ 0.2	— 0.4	— 1.2	

§§ Oxide.

(c) *Energy Quantization Theories*.—The most thoroughgoing of several investigations modifying Langevin's theory (p. 350) by introducing energy quantization, are those of Reiche (95) and Rotzahn (98). The theory so developed for gases leads to relations which frequently accord with the data for solids more satisfactorily than do those of Weiss and others, especially at very low temperatures. It accounts for the  $\Theta$  in Weiss's law and permits the computation of the value of  $\chi$  at 0°K, but it is consistent with only that type of cryomagnetic anomaly in which  $d(\chi^{-1})/dT$  decreases with  $T$ . For the equations and their derivation, see (67, 69).

TABLE 16.—REICHE-ROTZAHN THEORY AS APPLIED TO PARAMAGNETIC SOLIDS: ILLUSTRATIVE

$\chi_0$  = value of  $\chi$  at 0°K;  $\chi_{obs.}$ ,  $\chi_{calc.}$  = observed (51, 76, 79), calculated from Reiche-Rotzahn theory by means of parameters derived from the observations.  $\Delta = (\chi_{obs.} - \chi_{calc.})/\chi_{calc.}$ ;  $\Delta_m$  = mean value of  $\Delta$ ;  $[\Delta]_m$  = mean of the absolute values of  $\Delta$  (irrespective of sign);  $[\mu]_R$  and  $[\mu]_L$  =  $[\mu]$  of the gram-molecule, as derived from the Reiche-Rotzahn and the Langevin theory, respectively. Range of  $T$  = range over which the theory accords with observations.  $(\chi T)_L$ [( $\chi T$ )<sub>A</sub>] = value of  $\chi T$  at the lowest [highest] temperature of the range. Values of  $[\mu]_R$  are from (5); unit of  $\chi = 10^{-6}$ ; of  $\Delta_m$  and  $[\Delta]_m = 1\%$ ; of  $[\mu]_R$  and  $[\mu]_L = 10^{-20}$ ;  $T$  = absolute temperature, °K.

Solid	Range of $T$	$(\chi T)_L$	$(\chi T)_A$	$\Delta_m$
MnSO <sub>4</sub> .....	19.4–293.9	9 158	25 804	+0.50
MnSO <sub>4</sub> ·4H <sub>2</sub> O.....	14.4–288.7	17 755	19 141	— 0.47
FeSO <sub>4</sub> ·7H <sub>2</sub> O.....	14.7–293.2	11 113	12 394	+0.17
Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .....	64.0–289.8	11 334	15 446	+0.09

Solid	Range of $T$	$[\Delta]_m$	$\chi_0$	$[\mu]_R$	$[\mu]_L$
MnSO <sub>4</sub> .....	19.4–293.9	0.92	658	5.35	5.12
MnSO <sub>4</sub> ·4H <sub>2</sub> O.....	14.4–288.7	0.88	7 294	5.45	5.13
FeSO <sub>4</sub> ·7H <sub>2</sub> O.....	14.7–293.2	0.41	3 365	4.90	4.82
Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .....	64.0–289.8	0.27	286	6.84	7.11

(d) *Spatial Quantization Theories* (87, 103, 104).—The Zeeman spectroscopic effects suggest a spatial quantization of the axes of the elementary magnets. Pauli (87) introduced this assumption into Langevin's theory for gases (p. 350). As modified by Sommerfeld it gives  $\chi_a T (= C_a) = \left\{ \frac{[\mu]^2 N_0}{3R} \right\} \left\{ \frac{j_1 + 1}{j_1} \right\}$ , where  $[\mu]$  and  $j_1$  refer to the atom, and  $[\mu] = g j_1 [\mu_0]_B$  (see p. 346). Hence  $\sqrt{3RC_a/N_0}[\mu_0]_B (= 2.83\sqrt{C_a}) = g\sqrt{j_1(j_1 + 1)}$ . In certain cases,  $g$  and  $j_1$  can be determined with considerable certainty from chemical and spectroscopic data. The most conspicuous success in verifying the formula by such means has been obtained by Hund with the triply ionized rare earths,  $Z = 57$  to  $Z = 71$  (see Table 17). Similar attempts with ions of elements from  $Z = 18$  to  $Z = 29$  have been only partially successful, probably because at ordinary temperatures the atoms are not all in the state of excitation assumed to characterize the gas. For attempts at correlation between atomic constitution and magnetic moments,  $Z = 18$  to 29, see (20, 38, 53, 66, 104). For discussion of other theories of spatial quantization, see (73).



TABLE 17.—PAULI-SOMMERFELD THEORY AS APPLIED BY HUND TO THE RARE EARTHS (53, 54)

This theory requires that  $2.83\sqrt{C_a}$  ( $\equiv 2.83\sqrt{\chi_a T}$ ) shall equal  $g\sqrt{j_1(j_1 + 1)}$ , where  $g$  and  $j_1$  are numbers determined from spectroscopic and chemical data;  $gj_1 = [\mu]/[\mu_0]_B \equiv B$ . In the following it is supposed that the 4s and lower shells are completed, and that the 5s, 5p, and 5d shells contain 2, 2, and 4 electrons, respectively. In columns (3), (4), and (5) are given the number of electrons in the shells 4s, 4p, and 4d; in (6), the fundamental spectral term; in (9)  $B_c \equiv W/5$  for solid salt (Table 15); in (10),  $g\sqrt{j_1(j_1 + 1)}$ , computed value of  $2.83\sqrt{\chi_a T}$ ; in (11) and (12), values of  $2.83\sqrt{\chi_a T}$  as determined by Cabrera (20) and Meyer (74). Columns (4), (5), and (9) are not given by Hund.

(1) Z	(2) Ion*	(3) 4s	(4) 4p	(5) 4d	(6) Sp.	(7) $j_1$	(8) $g$	(9) $B_c$	(10) comp.	(11) obs.	(12) obs.
57	La.....	0	0	0	1S	0	8	0	0.00†	0	0
58	Ce.....	1	1	0	2F	2	4	2.38	2.54	2.39	2.77‡
59	Pr.....	2	2	0	3H	4	2	3.58	3.58	3.60	3.47
60	Nd.....	3	3	0	4J	6	2	3.60	3.62	3.62	3.51
61		4	4	0	5J	4	3		2.68		
62	Sa.....	5	5	0	6H	2	3	1.53	0.84	1.54(?)	1.32
63	Eu.....	6	6	0	7F	0	8	3.58	0.00†	3.61	3.12
64	Gd.....	7	6	1	8S	2	2	8.01	7.9	8.2	8.1
65	Tb.....	8	6	2	7F	6	2	9.58	9.7	9.6	9.0
66	Dy.....	9	6	3	6H	4	3	10.45	10.6	10.5	10.6
67	Ho.....	10	6	4	5J	8	2	10.4	10.6	10.5	10.4
68	Er.....	11	6	5	4J	6	3	9.4	9.6	9.5	9.4
69	Tm.....	12	6	6	3H	6	2	7.2	7.5	7.2	7.5
70	Yb.....	13	6	7	2F	2	4	4.4	4.5	4.4	4.6
71	Lu.....	14	6	8	1S	0	8	0	0.00†	0	0

\* Elements are triply ionized.

† Assumes  $g = 0$ .

‡ Perhaps  $\text{Pr}^{++}$ .

§ Discrepancy may be due to Gd as an impurity, or a considerable fraction of the Eu ions may not be in fundamental state.

## LITERATURE

(For a key to the periodicals see end of volume)

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PARAMAGNETIC AND DIAMAGNETIC DATA

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CONTENTS	PAGE
Volume susceptibility of gases.....	354
Specific susceptibility.....	
Elementary substances.....	354
Pure inorganic compounds.....	356
Pure organic compounds.....	361
Crystals.....	364
Miscellaneous substances.....	364
Solutions.....	364
Alloys and amalgams.....	365
Atomic and atomic group susceptibilities.....	365

The volume susceptibility ( $\kappa$ ), the specific susceptibility ( $\chi$ ), the magnetic field intensity ( $H$ ), the magnetic induction ( $B$ ), and the density ( $d$ ) of the material are related as indicated by the equations:  $B = (1 + 4\pi\kappa)H$ ,  $\chi = \kappa/d$ . In the following tables, the older measurements based upon  $\kappa$  for water have, so far as possible, been reduced to the basis of  $\kappa = -0.720 \times 10^{-6}$  for water at 20°C, which is the value now accepted for such work. The older measurements assumed  $\kappa = -0.75 \times 10^{-6}$  or  $-0.79 \times 10^{-6}$ . When not otherwise specified, room temperature is to be understood.

TABLE 1.—VOLUME SUSCEPTIBILITY ( $\kappa$ ) OF GASES  
Temperature = 20°C and pressure = 1A<sub>n</sub> except as noted; M = mean value; unit of  $\kappa = 10^{-9}$  cgsu

	$\kappa$	Lit.		$\kappa$	Lit.
A.....	-0.75	(47)	O.....	+142	M
H.....	-0.165	M		+140	(20)
	-0.166	(100)		+139	(100)
	-0.164	(125)		+144	(3)
He.....	-0.078	(47)		+145	(126)
N.....	-0.40	M	Air*.....	+ 29.0	M
	-0.31	(100)		+ 29.4	(20)
	-0.49	(47)		+ 28.7	(100)
Ne.....	-0.28	(47)		+ 29.4	(86, 122)
				+ 28.8	(10)

\* For  $\chi$ , see Table 6.

TABLE 2.—SPECIFIC SUSCEPTIBILITY ( $\chi$ ): ELEMENTARY SUBSTANCES

$g$  = gas at 1 atmosphere,  $l$  = liquid,  $s$  = solid,  $t$  = centigrade temperature, M = mean value; temperatures connected by } indicate the range over which  $\chi$  has been found to have the value stated; unit of  $\chi = 10^{-6}$  cgsu.

A-Table			Ag.—(Continued)		
$t$	$\chi$	Lit.	$t$	$\chi$	Lit.
20	-0.45 $g$	(47)	970	-0.28 $l$	(51)
	Ag.		1000	-0.28 $l$	(51)
18	-0.20	M	1125	-0.29 $l$	
- 170	-0.16	(79)		Al	
- 140	-0.17		18	0.63	M
- 80	-0.18		- 170	0.60	(79)
- 40	-0.19		18	0.65	(51)
18	-0.20	(51)	18	0.65	(51)
23	-0.20		230	0.64	
270	-0.23		500	0.57	
840	-0.24		657		
945	-0.26		658		
			1000	0.57 $l$	(51)

\* See Table 1.

TABLE 2.—(Continued)			C.—(Continued)		
$t$	$\chi$	Lit.	$t$	$\chi$	Lit.
18	-0.31	M	- 170	-6.0 $\dagger$	(79)
- 170	-0.31	(51, 79)	20	-3.5 $\dagger$	
164	-0.31		300	-2.7 $\dagger$	
			600	-2.0 $\dagger$	
			900	-1.4 $\dagger$	
18	-0.15	M	1000	-1.3 $\dagger$	
- 170	-0.15	(51, 79)	20	-2.0 $\dagger$	(51)
1060	-0.15		100	-2.0 $\dagger$	
1070	-0.17 $l$	(51)	500	-1.8 $\dagger$	
1230	-0.17 $l$		850	-1.6 $\dagger$	
			1150	-1.5 $\dagger$	
				Ca	
18	-0.69	M	- 170	1.10	(79)
- 170	-0.66	(79)	18		
18	-0.71	(51)		Cb	
100	-0.73		18	1.5	M
230	-0.76		- 170	1.65	(79)
330	-0.77		18		
1100	-0.77		18	1.3	(51)
			450		
				Cd	
- 170	0.9	(79)	18	-0.18	M
18			- 170	-0.18	(51, 79)
			300	-0.16	(51)
			400	-0.15	
- 170	-0.75	(79)	500		
20	-1.0		700		
300	-1.2			Ce	
			- 170	38	(79)
			- 150	35	
			- 100	26	
			18	15	
18	-1.35	M	100	12	
- 259	-1.55	(78)	200	11	
18	-1.27			Cl	
- 160	-1.63	(79)	- 60	-0.57 $l$	(51)
- 100	-1.52			Cr	
- 60	-1.44		18	3.6	M
20	-1.40		- 170	3.5	(79)
18	-1.38	(51)	18	3.7	(51)
150	-1.19		18	3.8	
260	-1.02		500	4.0	
280	-0.08 $l$	(51)	850	4.2	
600	-0.08 $l$		1100		
				Cs	
			- 170	-0.10	(79)
			18		
				Cu	
18	-0.39 $l$	M	18	-0.086	M
- 170	-0.40 $s$	(79)	- 170	-0.085	(79)
- 8	-0.40 $l$	(79)	20	-0.086	(51)
- 7	-0.40 $l$	(79)	18	-0.086	(51)
18	-0.39 $l$	(51)	100	-0.075	
18	-0.38 $l$	(51)	500	-0.070	
			850		
			1050		
				C	
- 170	-0.49*	(79)			
20	-0.49*	(51)			
20	-0.49*				
200	-0.50*				
400	-0.51*				
900	-0.54*				
1200	-0.56*				

\* Diamond. † Ceylon graphite. ‡ Gas carbon.



TABLE 2.—(Continued)

Er			K			P			Rb		
<i>t</i>	<i>x</i>	Lit.	<i>t</i>	<i>x</i>	Lit.	<i>t</i>	<i>x</i>	Lit.	<i>t</i>	<i>x</i>	Lit.
18	22	(53)	18	0.52	M	20	-0.90*	M	18	0.09	M
- 170	Ga	(79)	- 170	0.52	(51, 79)	- 170	-0.90*	(51, 79)	- 170	0.08	(79)
18	-0.26		62			44			38		(53)
30	-0.24		63	0.52 <sub>l</sub>	(51)	20	-0.67†	(20)	18	0.09	(53)
30	-0.23		190			45			Rh		
30	-0.04 <sub>l</sub>	(79)	La			120	-0.90 <sub>l</sub>	(51)	18	1.11	M
100			- 170	1.04	(79)	Pb			- 180	0.90	(79)
Ge			18			18	-0.12	M	- 100	1.02	
- 170	-0.30	(79)	Li			- 170	-0.14	(79)	- 40	1.05	
18	-0.12		- 170	0.50	(79)	80	-0.13		18	1.08	
200	-0.10		16			18	-0.12		18	1.14	(51)
890	-0.30 <sub>l</sub>	(79)	Mg			18	-0.12	(51)	280	1.31	
900	-0.39 <sub>l</sub>		18	0.55	(51)	330			500	1.46	
1000			650	0.55 <sub>l</sub>	(51)	330	-0.08 <sub>l</sub>	(51)	730	1.52	
H*			Mn			Pd			915	1.74	
20	-1.97 <sub>g</sub>	M	18	9.9	M	18	5.4	M	1140	1.86	
20	-1.98 <sub>g</sub>	(100)	18	9.7	(55)	- 258	10.9	(77)	Ru		
20	-1.96 <sub>g</sub>	(125)	100	10.0	(53)	- 253	9.9		18	0.50	M
	-2.7 <sub>l</sub>	(78)	Mo			- 196	8.1		- 170	0.55	(79)
He*			18	0.04	(51)	- 103	6.9		- 100	0.50	
20	-0.47 <sub>g</sub>	(47)	1250			- 61	6.0		- 40	0.46	
Hg			N*			- 23	5.8		18	0.43	
18	-0.19 <sub>l</sub>	M	20	-0.342 <sub>g</sub>	M	18	5.3		18	0.56	(51)
- 130	-0.155 <sub>s</sub>	(80)	20	-0.265 <sub>g</sub>	(100)	- 170	6.7	(79)	650	0.64	
- 40	-0.15 <sub>s</sub>	(79)	20	-0.419 <sub>g</sub>	(47)	- 100	6.2		750	0.65	
- 80	-0.18 <sub>l</sub>	(79)	Na			- 60	5.8		1000	0.70	
- 38	-0.18 <sub>l</sub>	(79)	18	0.51	M	18	5.2	(51)	1100	0.75	
18	-0.185 <sub>l</sub>	(80)	- 170	0.51	(51, 79)	18	5.8		S		
- 20	-0.193 <sub>l</sub>	(51)	97			200	4.6		18	-0.49†	M
I			Nd			470	3.4		- 170	-0.49†	(51, 79)
18	-0.36	M	18	36	(79)	750	2.6		112		
- 160	-0.30	(79)	Ne*			940	2.2		113	-0.49 <sub>l</sub>	(51, 79)
- 100	-0.32		20	-0.33 <sub>g</sub>	(47)	1230	1.7†		220		
- 60	-0.33		O*†			Pr			Sb		
0	-0.35		20	106.2 <sub>g</sub>	M	- 170	90	(79)	18	-0.87	M
20	-0.36		- 259	54 <sub>s1</sub>	(78)	- 100	53		- 175	-0.82	(79)
18	-0.35	(20)	- 252	56 <sub>s1</sub>		20	25		18	-0.92	(51)
113	-0.35	(51)	- 240	60 <sub>s1</sub>	(78)	200	14		80	-0.89	
25	-0.37		- 240	118 <sub>s2</sub>		400	11		150	-0.77	
50	-0.38		- 230	115 <sub>s2</sub>		600	8		300	-0.55	
95	-0.39		- 219	113 <sub>s2</sub>	(78)	900			550	-0.55	
113	-0.39 <sub>l</sub>	(51)	- 219	310 <sub>l</sub>	(78)	970	7 <sub>l</sub>	(79)	640	-0.49 <sub>l</sub>	(51)
140	-0.35 <sub>l</sub>		- 213	295 <sub>l</sub>		Pt			800		
160	-0.33 <sub>l</sub>		- 203	273 <sub>l</sub>		18	1.10	M	Se		
113	-0.35 <sub>l</sub>	(20)	- 196	260 <sub>l</sub>		- 170	1.31	(79)	18	-0.32	M
164			20	104.7 <sub>g</sub>	(20)	- 140	1.24		- 170	-0.32	(51, 79)
In			20	104.1 <sub>g</sub>	(100)	- 100	1.20		219		
20	-0.11	(51)	20	107.7 <sub>g</sub>	(3)	- 60	1.17		219	-0.32 <sub>l</sub>	(51)
Ir			20	108.2 <sub>g</sub>	(126)	20	1.13		250		
18	0.14	M	Os			18	1.10	(51)	Si		
- 170	0.13	(79)	18	0.05	M	250	0.66		18	-0.13	M
18	0.15	(51)	- 170	0.05	(51, 79)	450	0.56		- 170	-0.13	(51, 79)
200	0.17		1100			700	0.45		1000		
450	0.20		Sn			960	0.37		Sn		
850	0.26		18	0.025	M	1220	0.30		18	0.02	(79)
1150	0.31		18	0.02	(79)				18	0.027	(51)
			230	-0.35‡	(51)				240	-0.036 <sub>l</sub>	(51)
			400								

\* See Table 1. † Two modifications (*s*<sub>1</sub>, *s*<sub>2</sub>) of solid O.

\* White. † Red. ‡ Rhombic. § Gray.



TABLE 3.—(Continued)

\* Two modifications ( $\alpha, \beta$ ) of Tl.

$t$  = centigrade temperature;  $g$  = gas at 1 atmosphere;  $l$  = liquid;  $s$  = solid;  $Aq$  = determined from measurements of aqueous solutions, assuming the simple additivity relation is applicable to  $\chi$ . St. Meyer's original data (<sup>73</sup>) assume for Hg, at 18°C,  $\chi = -0.151 \times 10^{-6}$ ; for this table they have been multiplied by 19/15; unit of  $\chi = 10^{-6}$  cgsm.

Formula	<i>t</i>	$\chi$	Lit.
H <sub>2</sub> O.....	20	- 0.720 <i>l</i>	M (21, 55, 89, 98, 122, 125)
	-120 to 0	- 0.699 <i>s</i>	(55)
HCl.....	22	- 0.661	(32)
SO <sub>2</sub> .....		- 0.285 <i>l</i>	(82)
SO <sub>3</sub> .....	16	- 0.289	(82)

Formula	<i>t</i>	<i>x</i>	Lit.
H <sub>2</sub> SO <sub>4</sub> .....	22	- 0.441	(32)
H <sub>2</sub> SeO <sub>3</sub> .....	18	- 0.36	(73)
TeO <sub>2</sub> .....	18	- 0.14	(73)
H <sub>2</sub> TeO <sub>3</sub> .....	15	- 0.24	(73)
H <sub>2</sub> TeO <sub>4</sub> .....	18	- 0.43	(73)
NO.....	22	48.66 <i>g</i>	(100)
NO <sub>2</sub> .....	135	3.26 <i>g</i>	(100)
N <sub>2</sub> O.....	12	- 0.429 <i>l</i>	(100)
	16	- 0.429 <i>g</i>	(100)
N <sub>2</sub> O <sub>3</sub> .....	18	- 0.206 <i>l</i>	(100)
N <sub>2</sub> O <sub>4</sub> .....	- 16	- 0.276 <i>s</i>	(100)
N <sub>2</sub> O <sub>5</sub> .....	16	- 0.332 <i>s</i>	(100)
NH <sub>3</sub> .....	16	- 1.1 <i>g</i>	(81)
HNO <sub>2</sub> .....	22	- 0.467	(32)
NH <sub>2</sub> HSO <sub>3</sub> .....		- 0.441	(84)
P <sub>2</sub> O <sub>5</sub> .....	18	- 0.46	(73)
(NH <sub>4</sub> )H <sub>2</sub> PO <sub>4</sub> .....		- 0.50	(71)
As <sub>2</sub> O <sub>3</sub> .....	18	- 0.27	(73)
As <sub>2</sub> S <sub>3</sub> .....	18	- 0.03	(73)
Sb <sub>2</sub> O <sub>3</sub> .....	14	- 0.19	(73)
SbF <sub>3</sub> .....		- 0.255	(84)
SbCl <sub>3</sub> .....		- 0.364	(82)
SbCl <sub>5</sub> .....		- 0.371	(82)
SbBr <sub>3</sub> .....		- 0.275	(82)
Bi <sub>2</sub> O <sub>3</sub> .....		- 0.170	(32)
HBiO <sub>2</sub> .....	15	- 0.22	(73)
BiCl <sub>3</sub> .....		- 0.322	(44)
BiBr <sub>3</sub> .....		- 0.328	(44)
BiI <sub>3</sub> .....	20	- 0.49	(73)
Bi <sub>2</sub> S <sub>3</sub> .....		- 0.385	(44)
Bi <sub>2</sub> Se <sub>3</sub> .....		- 0.342	(44)
Bi(NO <sub>3</sub> ) <sub>3</sub> .5H <sub>2</sub> O.....		- 0.365	(44)
CO <sub>2</sub> .....	20	- 0.423 <i>g</i>	(100)
CS <sub>2</sub> .....		- 0.54	(71)
Bi <sub>2</sub> (CO <sub>3</sub> ) <sub>3</sub> .....		- 0.16	(73)
SiO <sub>2</sub> ( <i>cf.</i> p. 341).....		- 0.493	(83)
SiO(OH) <sub>2</sub> .....		- 0.427	(83)
Si(OH) <sub>4</sub> .....		- 0.443	(83)
Si <sub>2</sub> O(OH) <sub>6</sub> .....		- 0.429	(83)
SiCl <sub>4</sub> .....		- 0.537	(82)
SiCl <sub>3</sub> .SiCl <sub>3</sub> .....		- 0.513	(82)
SiHCl <sub>3</sub> .....		- 0.515	(82)
SiBr <sub>4</sub> .....		- 0.360	(82)
Si(OC <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> .....		- 0.663	(83)
Si <sub>2</sub> O(OC <sub>2</sub> H <sub>5</sub> ) <sub>6</sub> .....		- 0.635	(83)
SiC <sub>2</sub> H <sub>4</sub> Cl <sub>2</sub> .....		- 0.593	(82)
TiO <sub>2</sub> .....		0.066	(115)
Ti <sub>2</sub> O <sub>3</sub> .....		8.1	(115)
TiS <sub>2</sub> .....		0.56	(115)
Ti <sub>2</sub> S <sub>3</sub> .....		0.91	(115)
ZrO <sub>2</sub> .....	15	- 0.112	(73)
SnO.....	17	- 0.11	(73)
SnO <sub>2</sub> .....	15	- 0.050	(73)
Sn <sub>2</sub> O <sub>3</sub> .....	16	- 0.33	(73)
SnO(OH) <sub>2</sub> .....		- 0.278	(84)
Sn(OH) <sub>4</sub> .....		- 0.321	(84)
SnCl <sub>2</sub> .....	18	- 0.37	(73)
SnCl <sub>4</sub> .....		- 0.442	(81)
SnBr <sub>4</sub> .....		- 0.354	(81)
SnSO <sub>4</sub> .....	18	- 0.29	(73)
Sn(CH <sub>3</sub> ) <sub>4</sub> .....		- 0.218	(82)
Sn(C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> .....		- 0.138	(82)
Sn(C <sub>4</sub> H <sub>9</sub> ) <sub>4</sub> .....		- 0.085	(82)



TABLE 3.—(Continued)

Formula	$t$	$\chi$	Lit.	Formula	$t$	$\chi$	Lit.
$\text{SnO}(\text{OH})(\text{CH}_3)$ .....		- 0.324	(84)	$\text{MnO}$ .....	-189	89.9	(53)
$\text{PbO}$ .....	18	- 0.13	(73)		21	75.9	(53)
$\text{Pb}_2\text{O}_4$ .....	18	- 0.24	(73)		419	51.8	(53)
$\text{PbF}_2$ .....	16	- 0.24	(73)	$\text{MnO}_2$ .....	-186	75.9	(53)
$\text{PbCl}_2$ .....	15	- 0.32	(73)		21	38.4	(53)
$\text{PbBr}_2$ .....	20	- 0.28	(73)		503	22.7	(53)
$\text{PbI}_2$ .....	19	- 0.33	(73)	$\text{Mn}_2\text{O}_3$ .....	-184	150.0	(53)
$\text{Pb}(\text{NO}_3)_2$ .....		- 0.248	(112)		21	69.0	(53)
$\text{Th}(\text{NO}_3)_4$ .....		- 0.14	(73)		388	42.9	(53)
$\text{InCl}_3$ .....	18	- 0.39	(73)		928	29.5	(53)
$\text{In}_2\text{S}_3$ .....	20	- 0.19	(73)	$\text{Mn}_2\text{O}_4$ .....	-175	126.0	(53)
$\text{TiCl}_3$ .....	20	- 0.19	(73)		20	55.8	(53)
$\text{TiCl}_3$ .....	20	- 0.23	(73)		497	34.9	(53)
$\text{Ti}_2\text{SO}_4$ .....	20	- 0.25	(73)		1081	25.6	(53)
$\text{TiNO}_2$ .....	20	- 0.20	(73)	$\text{Mn}(\text{OH})_2$ .....		49	(92)
$\text{ZnO}$ .....		- 0.362	(32)	$\text{MnF}_2$ .....	18	155Aq	(56)
$\text{Zn}(\text{OH})_2$ .....		- 0.487	(127)	$\text{MnCl}_2$ .....	-179	393	(55)
$\text{ZnCl}_2$ .....	22	- 0.47Aq	(62)		24	107.0	(55)
$\text{ZnBr}_2$ .....	19	- 0.40	(73)		556	35.8	(55)
$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ .....		- 0.48	(71)	$\text{MnBr}_2$ .....	18	68Aq	(65)
$\text{CdO}$ .....	15	- 0.30	(73)	$\text{MnI}_2$ .....	18	47	(65)
$\text{CdCl}_2$ .....	18	- 0.32	(73)	$\text{MnS}$ .....	10	44.32	(116)
$\text{CdBr}_2$ .....	18	- 0.38	(73)	$\text{MnSO}_4$ .....	-178	261.0	(53)
$\text{CdI}_2$ .....	18	- 0.32	(73)		24	88.5	(53)
$\text{HgO}$ .....	16	- 0.24	(73)		747	30.0	(53)
$\text{HgCl}_2$ .....	19	- 0.23	(73)	$\text{Mn}_5\text{N}_2$ .....		15 000	(55)
$\text{HgCl}_2$ .....	17	- 0.19	(73)	$\text{Mn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ .....		45.5	(32)
$\text{HgBr}_2$ .....	15	- 0.30	(73)	$\text{MnSO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$ ...	-258.26	756	(57)
$\text{HgI}_2$ .....	17	- 0.33	(73)		-252.76	547	(57)
$\text{HgS}$ .....	16	- 0.23	(73)		-195.74	141.4	(57)
$\text{Hg}(\text{CH}_3)_2$ .....		-46	(83)		-104.0	65.6	(57)
$\text{Hg}(\text{C}_2\text{H}_5)_2$ .....		-40.8	(83)		16.6	37.8	(57)
$\text{Hg}(\text{C}_4\text{H}_9)_2$ .....		-36.1	(83)	$\text{MnPO}_4$ .....		69Aq	(117)
$\text{Hg}(\text{C}_6\text{H}_{11})_2$ .....		-35.4	(83)	$\text{Fe}_2\text{O}_3$ .....	18	20.6	(53)
$\text{CuO}$ .....		3.8	(127)	$\text{Fe}(\text{OH})_3$ .....		157	(73)
$\text{Cu}_2\text{O}$ .....		1.2	(127)	$\text{FeF}_3 \cdot 3\text{H}_2\text{O}$ .....	-162	55.0	(55)
$\text{Cu}(\text{OH})_2 \cdot \text{CuO}$ .....		5.0	(127)		17	47.3	(55)
$\text{CuCl}_2$ .....	-159	19.50	(55)		99	42.8	(55)
	19	9.10	(55)	$\text{FeCl}_2$ .....	-182	449	(55)
	503	3.82	(55)		17	101.2	(55)
$\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ .....	17	8.35	(36)		473	36.8	(55)
$\text{CuBr}_2$ .....	-177	2.88	(55)	$\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ .....	-181	210.0	(55)
	- 99	3.30	(55)		19	60.1	(55)
	31	3.10	(55)		65	52.3	(55)
	282	2.25	(55)	$\text{FeCl}_3$ .....	-174	252.0	(55)
$\text{CuS}$ .....	17	- 0.20	(73)		20	86.2	(55)
$\text{Cu}_2\text{S}$ .....	18	- 0.18	(73)		135	60.9	(55)
$\text{CuSO}_4$ .....		8.6	(36)	$\text{FeBr}_3$ .....	18	48Aq	(65)
$\text{CuSO}_4 \cdot \text{H}_2\text{O}$ .....		8.6	(36)	$\text{FeI}_2$ .....	18	40Aq	(65)
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ .....		5.9	(36)	$\text{FeSO}_4$ .....	-258.7	335	(57)
$\text{Cu}_2\text{Se}$ .....	17	- 0.19	(73)		-253.0	402	(57)
$\text{Cu}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ .....		5.50	(32)		-195.8	200.4	(57)
$\text{CuCl}_2 \cdot 2\text{NH}_4\text{Cl}$ .....	17	5.23	(36)		-103.5	107.2	(57)
$\text{CuCl}_2 \cdot 2\text{NH}_4\text{Cl} \cdot 2\text{H}_2\text{O}$ .....	17	4.95	(36)		17.1	67.6	(57)
$\text{Cu}_3\text{P}_2$ .....	18	- 0.23	(73)		19	74.2	(55)
$\text{Cu}(\text{CH}_3\text{CO}_2)_2 \cdot \text{H}_2\text{O}$ .....		3.27	(32)		642	24.0	(55)
$\text{AgCl}$ .....	17	- 0.35	(73)	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ .....	-259.17	757	(57)
$\text{AgBr}$ .....	19	- 0.33	(73)		-252.77	555	(57)
$\text{AgI}$ .....	19	- 0.37	(73)		-195.65	154.5	(57)
$\text{AuCl}_3$ .....	21	0.43	(73)		16.5	41.5	(57)
$\text{PtCl}_2$ .....	15	- 0.024	(73)	$\text{Fe}_2(\text{SO}_4)_3$ .....	-177	133.2	(55)
$\text{PtCl}_4$ .....	22	0.0Aq	(62)		23	57.3	(55)
$(\text{NH}_4)_2\text{PtCl}_6$ .....		- 0.42	(36)		658	20.9	(55)



TABLE 3.—(Continued)

Formula	<i>t</i>	<i>x</i>	Lit.	Formula	<i>t</i>	<i>x</i>	Lit.
Fe(NO <sub>3</sub> ) <sub>3</sub> ·6H <sub>2</sub> O		31.3	(32)	Co(C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> ) <sub>3</sub>	-134	1.157	(55)
FeF <sub>3</sub> ·NH <sub>4</sub> F		66.1	(36)		-20	0.644	(55)
FeF <sub>3</sub> ·2NH <sub>4</sub> F·H <sub>2</sub> O		73	(36)		28	0.569	(55)
FeCl <sub>3</sub> ·2NH <sub>4</sub> Cl·H <sub>2</sub> O	-199	132.7	(55)	[Co(NH <sub>3</sub> ) <sub>5</sub> H <sub>2</sub> O] <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub>		-0.218	(36)
	-100	74.3	(55)	CoSO <sub>4</sub> ·CuSO <sub>4</sub> ·6H <sub>2</sub> O		26	(34)
	16	47.3	(55)	NiO		53.7	(127)
FeSO <sub>4</sub> ·(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	18	43Aq	(65)	Ni(OH) <sub>2</sub>		48.3	(127)
FeSO <sub>4</sub> ·(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> ·6H <sub>2</sub> O	-258.6	547	(57)	NiF <sub>2</sub>	18	44Aq	(65)
	-252.8	413	(57)	NiCl <sub>2</sub>	-163	265.7	(55)
	-196.0	121.6	(57)		24	44.7	(55)
	17.2	32.6	(57)		847	10.0	(55)
Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	-178	151.9	(55)	NiBr <sub>2</sub>	18	19Aq	(65)
	28	50.5	(55)	NiSO <sub>4</sub>	-258.4	80.6	(57)
	410	23.0	(55)		-252.77	81.7	(57)
Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> ·24H <sub>2</sub> O	-258.4	598	(77)		-195.7	62.8	(57)
	-253	432	(77)		-103.9	39.9	(57)
	-196	114.7	(77)		15.9	26.7	(57)
	17	30.4	(77)		24	27.1	(55)
Fe(CO) <sub>5</sub>	19	-0.40	(80)		343	15.0	(55)
Cu[Fe(CN) <sub>6</sub> ]NO		5.73	(45)		763	10.2	(55)
Cu[Fe(CN) <sub>6</sub> ]NO·2H <sub>2</sub> O		4.57	(45)	NiSO <sub>4</sub> ·H <sub>2</sub> O		24.1	(36)
CoO		74.5	(127)	NiSO <sub>4</sub> ·6H <sub>2</sub> O		15.6	(36)
Co <sub>2</sub> O <sub>3</sub>		34.3	(127)	NiSO <sub>4</sub> ·7H <sub>2</sub> O	-258.5	294.0	(57)
Co <sub>3</sub> O <sub>4</sub>		39 to 43.6	(127)		-252.77	222.0	(57)
CoF <sub>2</sub>	18	103Aq	(65)		-195.81	77.3	(57)
CoCl <sub>2</sub>	-180	403.0	(55)		-103.5	34.8	(57)
	25	90.5	(55)		19.1	16.0	(57)
	628	26.5	(55)	NiSO <sub>4</sub> ·(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> ·6H <sub>2</sub> O	-258.6	207.5	(57)
CoBr <sub>2</sub>		46.8Aq	(33)		-252.8	150.4	(57)
CoI <sub>2</sub>	18	32Aq	(65)		-195.95	39.5	(57)
CoSO <sub>4</sub>	-258.33	462	(57)		-103.6	18.93	(57)
	-252.65	379	(57)		13.4	10.68	(57)
	-195.83	169.7	(57)	Ni(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		13.6	(32)
	-103.33	97.0	(57)	Ni(CO) <sub>4</sub>	19	-0.481	(80)
	16.6	62.2	(57)	CrO <sub>3</sub>	17	0.51	(53)
	22	59.6	(55)		142	0.51	(53)
	707	18.8	(55)	Cr <sub>2</sub> O <sub>3</sub>	-186	20.1	(53)
CoSO <sub>4</sub> ·H <sub>2</sub> O		53.6	(36)		-64	22.2	(53)
CoSO <sub>4</sub> ·7H <sub>2</sub> O	-258.34	535.9	(57)		18	25.5	(53)
	-252.7	403.0	(57)		117	25.6	(53)
	-195.62	126.5	(57)		797	16.4	(53)
	-103.6	61.6	(57)		1335	12.6	(53)
	19.9	37.0	(57)	Cr <sub>2</sub> O <sub>3</sub> ·4H <sub>2</sub> O	-183	110.5	(55)
CoH <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		64	(34)		-88	61.4	(55)
Co(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O		33.1	(32)		16	41.1	(55)
[Co(NH <sub>3</sub> ) <sub>5</sub> H <sub>2</sub> O](NO <sub>3</sub> ) <sub>2</sub> ·H <sub>2</sub> O		0.112	(36)	Cr <sub>2</sub> O <sub>3</sub> ·7H <sub>2</sub> O	-164	93.5	(55)
[(Co(NH <sub>3</sub> ) <sub>5</sub> H <sub>2</sub> O)(NO <sub>3</sub> ) <sub>4</sub> ·2H <sub>2</sub> O]		-0.092	(36)		-68	54.9	(55)
[Co(NH <sub>3</sub> ) <sub>4</sub> Cl]Cl		-0.022	(36)		19	40.0	(55)
[Co(NH <sub>3</sub> ) <sub>3</sub> Cl]Cl <sub>2</sub>		-0.295	(36)	Cr(OH) <sub>2</sub>		48.5Aq	(92)
[Co(NH <sub>3</sub> ) <sub>2</sub> Cl] <sub>2</sub>		-0.38	(36)	H <sub>2</sub> CrO <sub>4</sub>	17	0.70	(73)
[Co(NH <sub>3</sub> ) <sub>5</sub> H <sub>2</sub> O]Cl <sub>2</sub>		-0.306	(36)	Cr <sub>2</sub> (OH) <sub>6</sub> ·H <sub>2</sub> O		45.5	(127)
[Co(NH <sub>3</sub> ) <sub>6</sub> ]I <sub>3</sub>		-0.10	(36)	CrCl <sub>2</sub>		84Aq	(117)
CoSO <sub>4</sub> ·(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	19	37Aq	(93)	CrCl <sub>3</sub>	-168	176.5	(52)
CoSO <sub>4</sub> ·(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> ·6H <sub>2</sub> O	-258.32	322	(57)		19	44.3	(52)
	-252.8	241	(57)		806	10.3	(52)
	-195.82	78.4	(57)	Cr <sub>2</sub> OCl <sub>4</sub> (violet)		46Aq	(15)
	27.7	24.6	(57)	(green)		43Aq	(15)
[Co(NH <sub>3</sub> ) <sub>5</sub> HSO <sub>4</sub> ] <sub>2</sub> SO <sub>4</sub>		-1.33	(36)	CrS	20	28.4	(116)
[Co(NH <sub>3</sub> ) <sub>5</sub> ] <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·5H <sub>2</sub> O		-0.315	(36)	Cr <sub>2</sub> S <sub>3</sub>	18	23.3	(116)
Co[CH(COCH <sub>3</sub> ) <sub>2</sub> ] <sub>2</sub>		30.2	(36)	Cr <sub>2</sub> S <sub>4</sub>	16	33.3	(116)
				CrSO <sub>4</sub>		66Aq	(15)
				Cr <sub>2</sub> O(SO <sub>4</sub> ) <sub>2</sub> (violet)		38Aq	(15)
				(green)		36Aq	(15)
				Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	-180	97.0	(55)



TABLE 3.—(Continued)

Formula	<i>t</i>	<i>x</i>	Lit.	Formula	<i>t</i>	<i>x</i>	Lit.
Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> —(Continued)	21	29.5	(55)	Pr <sub>4</sub> O <sub>7</sub>	15	16	(73)
	650	9.7	(55)	PrCl <sub>3</sub>	19	17	(73)
Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·9H <sub>2</sub> O	17	23.2	(55)	Pr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		13.7	(76)
Cr(NO <sub>3</sub> ) <sub>3</sub> ·9H <sub>2</sub> O		13.75	(32)	Neodymium oxide	23	29.3	(124)
[Cr(NH <sub>3</sub> ) <sub>4</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub> ][Cr-					179	19.8	(124)
(NH <sub>3</sub> ) <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub> ·3H <sub>2</sub> O		24.4	(36)		283	16.6	(124)
[Cr(NH <sub>3</sub> ) <sub>4</sub> ][Cr(C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub> ]-				Nd <sub>2</sub> O <sub>3</sub>		30.3	(114)
3H <sub>2</sub> O		24.4	(36)	Nd <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		18.3	(114)
[Cr(NH <sub>3</sub> ) <sub>4</sub> ][Co(C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub> ]-				Nd(NO <sub>3</sub> ) <sub>3</sub> ·2NH <sub>4</sub> NO <sub>3</sub>	18	11	(73)
3H <sub>2</sub> O		15.5	(36)	Nd(NO <sub>3</sub> ) <sub>3</sub> ·2NH <sub>4</sub> NO <sub>3</sub> ·4H <sub>2</sub> O	18	8.7	(73)
[Cr(C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> ][Co(NH <sub>3</sub> ) <sub>6</sub> ]-				Nd <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub>		14.7	(76)
3H <sub>2</sub> O		11.65	(36)	Sa <sub>2</sub> O <sub>3</sub>	22	6.02	(124)
MoO <sub>3</sub>	20	0.33	(116)		102	5.93	(124)
MoO <sub>3</sub>	20	0.88	(116)		270	5.98	(124)
Mo <sub>2</sub> O <sub>3</sub>	16	-0.35	(73)	SaSO <sub>4</sub>		3.43	(36)
Mo <sub>2</sub> O <sub>3</sub>	16	0.30	(116)	SaSO <sub>4</sub> ·8H <sub>2</sub> O		2.6	(36)
H <sub>2</sub> MoO <sub>4</sub>	14	-0.015	(73)	Gd <sub>2</sub> O <sub>3</sub>	20	130.1	(124)
MoS <sub>2</sub>	16	-0.33	(73)		180	85.5	(124)
WO <sub>3</sub>	15	0.81	(116)		280	67.8	(124)
H <sub>2</sub> WO <sub>4</sub>	18	-1.1	(73)	GdCl <sub>3</sub>	18	91	(27)
UO <sub>2</sub>	17	7.5	(116)	Gd <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		92.6	(36)
UO <sub>2</sub>	16	1.08	(116)	Gd <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·8H <sub>2</sub> O	-259.2	1468	(78)
U <sub>2</sub> O <sub>5</sub>	15	0.95	(116)		-256.1	1229	(78)
UCl <sub>4</sub>	19	-0.40	(73)		-252.8	1039	(78)
UO <sub>2</sub> (NO <sub>3</sub> ) <sub>2</sub>	15	-0.44	(73)		17	72.9	(78)
VO	15	50.1	(116)	Gd <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub>		25	(128)
VO <sub>2</sub>	13	3.73	(116)	Gd(C <sub>2</sub> H <sub>3</sub> SO <sub>4</sub> ) <sub>3</sub> ·9H <sub>2</sub> O	-258.5	699	(58)
V <sub>2</sub> O <sub>5</sub>	15	13.9	(116)		-253	154	(58)
V <sub>2</sub> O <sub>5</sub>	15	0.85	(116)		-104	59.1	(58)
VS	16	7.22	(116)		18	34.3	(58)
V <sub>2</sub> S <sub>3</sub>	16	8.95	(116)	Dy <sub>2</sub> O <sub>3</sub>	-259	2334	(77)
V <sub>2</sub> S <sub>3</sub>	15	12.6	(116)		-253	1915	(77)
NH <sub>4</sub> VO <sub>3</sub>	15	-0.12	(73)		-103	375	(77)
Cb <sub>2</sub> O <sub>6</sub>	20	-0.10	(73)		16	229	(77)
H <sub>2</sub> Ta <sub>2</sub> O <sub>7</sub>	20	0.29	(73)		180	153.9	(124)
B <sub>2</sub> O <sub>3</sub>	14	-0.55	(73)		300	122.6	(124)
H <sub>2</sub> BO <sub>3</sub>		-0.52	(71)	Ho <sub>2</sub> O <sub>3</sub>		243	(129)
BN	15	0.0	(73)	HoCl <sub>3</sub>		172	(129)
Al <sub>2</sub> O <sub>3</sub>		-0.098	(127)	Ho(NO <sub>3</sub> ) <sub>3</sub>		123.6	(129)
Al <sub>2</sub> O <sub>3</sub> ·2H <sub>2</sub> O		-0.337	(127)	Er <sub>2</sub> O <sub>3</sub>	20	189.1	(124)
AlCl <sub>3</sub>	19	-0.60	(73)		180	124.4	(124)
AlBr <sub>3</sub>	19	-0.32	(73)		280	102.2	(124)
Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	18	-0.48	(73)	ErCl <sub>3</sub>	18	114Aq	(27)
Sc <sub>2</sub> O <sub>3</sub>		-0.018	(71)	Er <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		118	(115)
Sc <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		-0.33	(114)	Er <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub>		94	(115)
Sc(NO <sub>3</sub> ) <sub>3</sub>	21	0.0	(73)	Yb <sub>2</sub> O <sub>3</sub>		38	(73)
Sc <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub>		-0.25	(71)	YbCl <sub>3</sub>		25Aq	(27)
Y <sub>2</sub> O <sub>3</sub>	22	0.53	(124)	HfO <sub>2</sub>		-0.110	(73)
YCl <sub>3</sub>	17	20	(73)	BeO	16	0.0	(73)
Y <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		-0.24	(114)	Be(OH) <sub>2</sub>		-0.537	(84)
Y <sub>2</sub> (CO <sub>3</sub> ) <sub>2</sub> ·3H <sub>2</sub> O	20	9.2	(73)	BeCl <sub>2</sub>	17	-0.60	(73)
La <sub>2</sub> O <sub>3</sub>	24	-0.40	(124)	BeSO <sub>4</sub>	18	-0.46	(73)
LaCl <sub>3</sub>	15	5.6	(73)	BeSO <sub>4</sub> ·4H <sub>2</sub> O	17	-0.51	(73)
La <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		-0.30	(114)	BeCO <sub>3</sub> ·2BeO	15	-0.34	(73)
La(NO <sub>3</sub> ) <sub>3</sub> ·2NH <sub>4</sub> NO <sub>3</sub>	15	-0.29	(73)	MgO	17	-0.25	(73)
CeO <sub>2</sub>		0.39	(71)	MgCl <sub>2</sub>	18	-0.58	(73)
CeCl <sub>3</sub>	19	6.1	(73)	MgCl <sub>2</sub> ·6H <sub>2</sub> O	18	-0.57	(73)
CeBr <sub>3</sub>	18	6.0Aq	(27)	MgBr <sub>2</sub>	20	-0.57	(73)
Ce <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		7.8	(114)	MgSO <sub>4</sub>		-0.45Aq	(103)
Ce(NO <sub>3</sub> ) <sub>3</sub> ·2NH <sub>4</sub> NO <sub>3</sub>	16	4.2	(73)	MgSO <sub>4</sub> ·7H <sub>2</sub> O		-0.551	(84)
Ce(CO <sub>3</sub> ) <sub>2</sub>	20	3.4	(73)	MgCO <sub>3</sub>		-0.51	(73)
Ce <sub>2</sub> (CO <sub>3</sub> ) <sub>3</sub>	15	9.0	(73)	MgCO <sub>3</sub> ·3H <sub>2</sub> O		-0.525	(84)
Pr <sub>2</sub> O <sub>3</sub>		15.6	(76)	Mg(C <sub>2</sub> H <sub>3</sub> SO <sub>4</sub> ) <sub>2</sub> ·2H <sub>2</sub> O		-0.525	(84)



TABLE 3.—(Continued)

Formula	<i>t</i>	$\chi$	Lit.	Formula	<i>t</i>	$\chi$	Lit.
CaO.....	16	— 0.27	(73)	NaCl.CuCl <sub>2</sub> .....	17	6.48	(36)
Ca(OH) <sub>2</sub> .....	16	— 0.39	(73)	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> .10H <sub>2</sub> O.....		— 0.59	(71)
CaF <sub>2</sub> .....		— 0.360	(84)	KOH.....	22	— 0.33Aq	(62)
CaCl <sub>2</sub> .....	17	— 0.49	(73)	KHF <sub>2</sub> .....		— 0.428	(32)
CaCl <sub>2</sub> .6H <sub>2</sub> O.....	17	— 0.54	(73)	KCl.....		— 0.516	(83)
CaSO <sub>4</sub> .....		— 0.364	(84)	KClO <sub>3</sub> .....		— 0.30	(71)
CaSO <sub>4</sub> .H <sub>2</sub> O.....		— 0.384	(84)	KBr.....		— 0.377	(32)
CaCO <sub>3</sub> .....		— 0.382	(84)	KI.....		— 0.422	(32)
SrO.....	20	— 0.060	(73)	K <sub>2</sub> SO <sub>4</sub> .....		— 0.403	(83)
SrF <sub>2</sub> .....		— 0.296	(84)	K <sub>2</sub> S <sub>2</sub> O <sub>8</sub> .....		— 0.371	(84)
SrCl <sub>2</sub> .....	20	— 0.56	(73)	K <sub>2</sub> S <sub>4</sub> O <sub>6</sub> .....		— 0.412	(84)
SrBr <sub>2</sub> .....	19	— 0.39	(73)	KNO <sub>3</sub> .....		— 0.326	(83)
SrI <sub>2</sub> .....	19	— 0.44	(73)	(KSO <sub>3</sub> ) <sub>2</sub> NQH.....		— 0.401	(84)
SrSO <sub>4</sub> .....		— 0.315	(84)	K <sub>2</sub> CO <sub>3</sub> .....		— 0.488	(32)
SrCO <sub>3</sub> .....		— 0.316	(84)	(COOK) <sub>2</sub> .H <sub>2</sub> O.....		— 0.77	(71)
BaO.....	20	— 0.13	(73)	[CH(OH)COOK] <sub>2</sub> .0.5H <sub>2</sub> O..		— 1.10	(71)
Ba(OH) <sub>2</sub> .....	18	— 0.32	(73)	KCNO.....		— 0.465	(85)
Ba(OH) <sub>2</sub> .8H <sub>2</sub> O.....		— 0.497	(83)	K <sub>2</sub> H(C <sub>2</sub> N <sub>2</sub> O <sub>3</sub> ).H <sub>2</sub> O.....		— 0.488	(85)
BaF <sub>2</sub> .....		— 0.291	(83)	SO <sub>3</sub> KCH(NH <sub>2</sub> )SO <sub>3</sub> H.....		— 0.424	(84)
BaCl <sub>2</sub> .....		— 0.41	(73)	KCl.CuCl <sub>2</sub> .....	17	6.03	(36)
BaCl <sub>2</sub> .2H <sub>2</sub> O.....		— 0.368	(32)	2KCl.CuCl <sub>2</sub> .....	17	4.28	(36)
BaBr <sub>2</sub> .....		— 0.39	(73)	2KCl.CuCl <sub>2</sub> .2H <sub>2</sub> O.....	17	4.30	(36)
BaBr <sub>2</sub> .2H <sub>2</sub> O.....		— 0.371	(32)	K <sub>2</sub> PtCl <sub>4</sub> .....		— 0.356	(36)
BaI <sub>2</sub> .....	22	— 0.39Aq	(62)	K <sub>2</sub> PtCl <sub>6</sub> .....		— 0.393	(36)
BaI <sub>2</sub> .2H <sub>2</sub> O.....	19	— 0.38	(73)	K <sub>2</sub> Pt(C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub> .2H <sub>2</sub> O.....		— 0.31	(36)
BaS.....	18	— 0.32	(73)	KMnO <sub>4</sub> .....	—170	0.179	(55)
BaSO <sub>4</sub> .....		— 0.306	(84)		21	0.175	(55)
BaS <sub>2</sub> O <sub>6</sub> .2H <sub>2</sub> O.....		— 0.359	(84)		95	0.175	(55)
Ba(NO <sub>3</sub> ) <sub>2</sub> .....		— 0.254	(84)		162	0.184	(55)
Ba <sub>3</sub> (AsO <sub>3</sub> ) <sub>2</sub> .....		— 0.280	(84)	K <sub>3</sub> Fe(CN) <sub>6</sub> .....	—148	14.43	(55)
BaCO <sub>3</sub> .....		— 0.298	(84)		— 70	9.96	(55)
Ba(MnO <sub>4</sub> ) <sub>2</sub> .....		10.1	(116)		21	7.08	(55)
Li <sub>2</sub> O.....	20	— 0.57	(73)	K <sub>4</sub> Fe(CN) <sub>6</sub> .3H <sub>2</sub> O.....		— 0.420	(80)
LiCl.....		— 0.573	(83)	K <sub>2</sub> SO <sub>4</sub> .CoSO <sub>4</sub> .6H <sub>2</sub> O.....	—258.36	321	(57)
Li <sub>2</sub> SO <sub>4</sub> .....	15	— 0.38	(73)		—252.68	243.5	(57)
Li <sub>2</sub> SO <sub>4</sub> .H <sub>2</sub> O.....	17	— 0.43	(73)		—195.73	75.1	(57)
LiNO <sub>3</sub> .....	19	— 0.48	(73)		—103.8	38.7	(57)
Li <sub>2</sub> CO <sub>3</sub> .....		— 0.413	(83)		17.9	23.4	(57)
NaOH.....	17	— 0.59	(73)	K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> .....		0.129	(32)
NaF.....	21	— 0.51	(73)	K <sub>2</sub> SO <sub>4</sub> .Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .24H <sub>2</sub> O....		11.5	(32)
NaCl.....	—150	— 0.501	(55)	K <sub>2</sub> SO <sub>4</sub> .Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .....	17	— 0.470	(55)
	18	— 0.499	(55)		— 84	— 0.476	(55)
	362	— 0.499	(55)		—159.7	— 0.480	(55)
	933	— 0.508	(55)	K <sub>2</sub> SO <sub>4</sub> .Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .24H <sub>2</sub> O....		— 0.579	(112)
NaBr.....	18	— 0.47	(73)	RbCl.....		— 0.327	(83)
NaI.2H <sub>2</sub> O.....		— 0.402	(32)	Rb <sub>2</sub> SO <sub>4</sub> .....		— 0.331	(83)
Na <sub>2</sub> SO <sub>3</sub> .7H <sub>2</sub> O.....		— 0.462	(84)	RbNO <sub>3</sub> .....		— 0.281	(83)
Na <sub>2</sub> SO <sub>4</sub> .10H <sub>2</sub> O.....		— 0.86	(71)	Rb <sub>2</sub> CO <sub>3</sub> .....		— 0.321	(83)
Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> .....		— 0.391	(84)	Rb <sub>2</sub> SO <sub>4</sub> .CoSO <sub>4</sub> .6H <sub>2</sub> O.....	—258.44	268.0	(57)
NaNO <sub>3</sub> .....		— 0.28	(71)		—252.77	201.0	(57)
NaH <sub>2</sub> PO <sub>4</sub> .....		— 0.381	(84)		—195.67	64.6	(57)
Na <sub>2</sub> HPO <sub>4</sub> .....		— 0.451	(84)		—103.65	34.1	(57)
Na <sub>2</sub> HPO <sub>4</sub> .....		— 0.399	(84)		14.9	21.0	(57)
AsO(ONa) <sub>3</sub> .12H <sub>2</sub> O.....		— 0.566	(84)	CsCl.....		— 0.363	(83)
Na <sub>2</sub> CO <sub>3</sub> .....	17	— 0.24	(73)	Cs <sub>2</sub> SO <sub>4</sub> .....		— 0.322	(83)
Na <sub>2</sub> CO <sub>3</sub> .10H <sub>2</sub> O.....	17	— 0.58	(73)	CsNO <sub>3</sub> .....		— 0.412	(83)
NaHCO <sub>3</sub> .....		— 0.21	(71)	Cs <sub>2</sub> CO <sub>3</sub> .....		— 0.320	(83)
NaC <sub>2</sub> H <sub>3</sub> O <sub>2</sub> .3H <sub>2</sub> O.....		— 0.50	(71)	Cs <sub>2</sub> SO <sub>4</sub> .Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .....	15	— 0.51	(73)
CH <sub>3</sub> AsO(ONa) <sub>2</sub> .H <sub>2</sub> O.....		— 0.529	(84)	Cs <sub>2</sub> SO <sub>4</sub> .Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .24H <sub>2</sub> O....	14	— 0.49	(73)
SnO(ONa) <sub>2</sub> .3H <sub>2</sub> O.....		— 0.370	(84)				



TABLE 4.—SPECIFIC SUSCEPTIBILITY ( $\chi$ ): PURE ORGANIC COMPOUNDSCentigrade temperature; where unindicated, room temperature is to be understood; unit of  $\chi = 10^{-6}$  cgs

C-Table, C-Arrangement; v. Vol. III, p. viii

Formula	Name (and temperature)	$\chi$	Lit.	Formula	Name (and temperature)	$\chi$	Lit.
$\text{CBr}_4$	Carbon tetrabromide.....	-0.293	(82)	$\text{C}_2\text{H}_7\text{O}_4\text{P}$	Ethyl phosphate.....	-0.539	(84)
$\text{CCl}_3\text{NO}_2$	Trichloronitromethane.....	-0.458	(82)	$\text{C}_3\text{H}_3\text{N}_3\text{O}_3$	Cyanuric acid.....	-0.490	(85)
$\text{CCl}_4$	Carbon tetrachloride.....	-0.429	(82)	$\text{C}_3\text{H}_3\text{N}_3\text{O}_3$	Cyamelide.....	-0.435	(85)
$\text{Cl}_4$	Carbon tetraiodide.....	-0.261	(82)	$\text{C}_3\text{H}_5\text{Br}_3$	1, 2, 3-Tribromopropane.....	-0.420	(82)
$\text{CN}_4\text{O}_3$	Tetranitromethane.....	-0.223	(82)	$\text{C}_3\text{H}_5\text{ClO}$	Chloroacetone.....	-0.550	(81)
$\text{CHBr}_3$	Bromoform.....	-0.316	(82)	$\text{C}_3\text{H}_5\text{NO}$	Ethyl isocyanate.....	-0.642	(85)
$\text{CHCl}_3$	Chloroform.....	-0.488	(82)	$\text{C}_3\text{H}_5\text{Cl}_2\text{O}$	1, 3-Dichloro-2-hydroxypropane.....	-0.621	(81)
$\text{CH}_2\text{Br}_2$	Methylene bromide.....	-0.379	(82)	$\text{C}_3\text{H}_6\text{O}$	<i>n</i> -Propionaldehyde.....	-0.585	(81)
$\text{CH}_2\text{Cl}_2$	Methylene chloride.....	-0.549	(81)	$\text{C}_3\text{H}_6\text{O}$	Acetone.....	-0.581	(81)
$\text{CH}_2\text{I}_2$	Methylene iodide.....	-0.349	(82)	$\text{C}_3\text{H}_6\text{O}_2$	Propionic acid.....	-0.587	(81)
$\text{CH}_2\text{O}$	Formaldehyde.....	-0.62	(71)	$\text{C}_3\text{H}_6\text{O}_2$	Ethyl formate.....	-0.581	(82)
$\text{CH}_3\text{O}_2$	Formic acid.....	-0.432	(81)	$\text{C}_3\text{H}_6\text{O}_2$	Methyl acetate.....	-0.590	(82)
$\text{CH}_3\text{Br}$	Methyl bromide.....	-0.603	(81)	$\text{C}_3\text{H}_7\text{Br}$	<i>n</i> -Propyl bromide.....	-0.527	(81)
$\text{CH}_3\text{Cl}$	Methyl chloride.....	-0.633	(81)	$\text{C}_3\text{H}_7\text{Br}$	Isopropyl bromide.....	-0.529	(81)
$\text{CH}_3\text{I}$	Methyl iodide.....	-0.403	(81)	$\text{C}_3\text{H}_7\text{Cl}$	Propyl chloride.....	-0.710	(81)
$\text{CH}_3\text{NO}$	Formamide.....	-0.486	(82)	$\text{C}_3\text{H}_7\text{ClO}_2$	1-Chloro-2, 3-dihydroxypropane.....	-0.604	(81)
$\text{CH}_4$	Methane.....	-2.5	(30, 31)	$\text{C}_3\text{H}_8\text{O}$	Propyl alcohol.....	-0.766	(81)
$\text{CH}_3\text{N}_2\text{O}$	Urea.....	-0.560	(82)	$\text{C}_3\text{H}_8\text{O}_2$	Methylal.....	-0.621	(82)
$\text{CH}_3\text{O}$	Methyl alcohol ( $-3^\circ$ ).....	-0.65	(55, 56)	$\text{C}_3\text{H}_8\text{O}_2$	Glycerol.....	-0.538	(71)
$\text{CH}_3\text{N}$	Methylamine.....	-0.870	(81)	$\text{C}_3\text{H}_{10}\text{N}_2$	Propylenediamine.....	-0.784	(81)
$\text{C}_2\text{Br}_2\text{Cl}_4$	1, 2-Dibromotetrachloroethane.....	-0.387	(82)	$\text{C}_4\text{H}_4\text{N}$	Tetraiodopyrrole.....	-0.331	(82)
$\text{C}_2\text{Br}_2\text{I}_2$	1, 2-Dibromodiodoethylene.....	-0.320	(82)	$\text{C}_4\text{H}_2\text{O}_3$	Maleic anhydride.....	-0.365	(45, 46)
$\text{C}_2\text{Br}_4$	Tetrabromoethylene.....	-0.334	(82)	$\text{C}_4\text{H}_4\text{O}_3$	Succinic anhydride.....	-0.475	(45, 46)
$\text{C}_2\text{Br}_6$	Hexabromoethane.....	-0.294	(82)	$\text{C}_4\text{H}_4\text{O}_4$	Maleic acid.....	-0.427	(45, 18)
$\text{C}_2\text{Cl}_4$	Tetrachloroethylene.....	-0.508	(81, 82)	$\text{C}_4\text{H}_4\text{O}_4$	Fumaric acid.....	-0.426	(45, 18)
$\text{C}_2\text{Cl}_6$	Hexachloroethane.....	-0.476	(82)	$\text{C}_4\text{H}_5\text{Cl}_3\text{O}_2$	Ethyl trichloroacetate.....	-0.520	(82)
$\text{C}_2\text{I}_4$	Tetraiodoethylene.....	-0.309	(82)	$\text{C}_4\text{H}_5\text{Br}_3\text{O}_2$	Ethyl tribromoacetate.....	-0.368	(82)
$\text{C}_2\text{N}_2$	Cyanogen.....	-0.415	(81)	$\text{C}_4\text{H}_5\text{NO}_2$	Succinimide.....	-0.477	(82)
$\text{C}_2\text{HCl}_3\text{O}$	Chloral.....	-0.459	(82)	$\text{C}_4\text{H}_6\text{O}_3$	Acetic anhydride.....	-0.517	(82)
$\text{C}_2\text{HCl}_5$	Pentachloroethane.....	-0.490	(82)	$\text{C}_4\text{H}_6\text{O}_4$	Succinic acid.....	-0.461	(45, 46)
$\text{C}_2\text{H}_2\text{BrFO}_2$	Fluorobromoacetic acid.....	-0.379	(82)	$\text{C}_4\text{H}_6\text{O}_4$	Dimethyl oxalate.....	-0.472	(82)
$\text{C}_2\text{H}_2\text{Br}_2$	1, 2-Dibromoethylene.....	-0.386	(82)	$\text{C}_4\text{H}_7\text{BrO}_2$	Ethyl bromoacetate.....	-0.496	(81)
$\text{C}_2\text{H}_2\text{Br}_2\text{Cl}_2$	1, 2-Dichloro-1, 2-dibromoethane.....	-0.423	(82)	$\text{C}_4\text{H}_7\text{ClO}_2$	Ethyl chloroacetate.....	-0.590	(81)
$\text{C}_2\text{H}_2\text{Br}_2\text{F}_2$	1-Difluoro-2-dibromoethane.....	-0.382	(82)	$\text{C}_4\text{H}_7\text{IO}_2$	Ethyl iodoacetate.....	-0.456	(81)
$\text{C}_2\text{H}_2\text{Br}_4$	1, 1, 2, 2-Tetrabromoethane.....	-0.357	(82)	$\text{C}_4\text{H}_7\text{N}$	Propyl cyanide.....	-0.714	(81)
$\text{C}_2\text{H}_2\text{Cl}_2$	1, 2-Dichloroethylene.....	-0.521	(82)	$\text{C}_4\text{H}_8\text{N}_2\text{O}_2$	Dimethyloxamide.....	-0.544	(82)
$\text{C}_2\text{H}_2\text{Cl}_4$	1, 1, 2, 2-Tetrachloroethane.....	-0.535	(82)	$\text{C}_4\text{H}_8\text{O}$	Butyraldehyde.....	-0.635	(81)
$\text{C}_2\text{H}_2\text{Br}_2\text{F}$	1, 2-Dibromo-2-fluoroethane.....	-0.379	(82)	$\text{C}_4\text{H}_8\text{O}$	Methyl ethyl ketone.....	-0.633	(82)
$\text{C}_2\text{H}_2\text{F}_2\text{NO}$	Difluoroacetamide.....	-0.433	(82)	$\text{C}_4\text{H}_8\text{O}_2$	<i>n</i> -Butyric acid.....	-0.632	(82)
$\text{C}_2\text{H}_4$	Ethylene.....	-1.6	(30, 31)	$\text{C}_4\text{H}_8\text{O}_2$	Isobutyric acid.....	-0.646	(81)
$\text{C}_2\text{H}_4\text{Br}_2$	Ethylene bromide.....	-0.422	(81)	$\text{C}_4\text{H}_8\text{O}_2$	Ethyl acetate ( $-149^\circ$ ).....	-0.581	(55, 56)
$\text{C}_2\text{H}_4\text{Cl}_2$	Ethylene chloride.....	-0.602	(81)		( $-6^\circ$ ).....	-0.607	(55, 56)
$\text{C}_2\text{H}_4\text{Cl}_2$	Ethylidene chloride.....	-0.580	(81)	$\text{C}_4\text{H}_8\text{O}_2$	Methyl propionate.....	-0.628	(82)
$\text{C}_2\text{H}_4\text{F}_2\text{O}$	Difluoroethanol.....	-0.503	(82)	$\text{C}_4\text{H}_8\text{NO}$	Isobutyraldoxime.....	-0.642	(82)
$\text{C}_2\text{H}_4\text{I}_2$	Ethylene iodide.....	-0.381	(82)	$\text{C}_4\text{H}_{10}\text{N}_2\text{O}$	Nitrosodiethylamine.....	-0.593	(82)
$\text{C}_2\text{H}_4\text{N}_2\text{O}_2$	Oxamide.....	-0.443	(82)	$\text{C}_4\text{H}_{10}\text{O}$	<i>n</i> -Butyl alcohol.....	-0.743	(71)
$\text{C}_2\text{H}_4\text{O}$	Acetaldehyde.....	-0.502	(81)	$\text{C}_4\text{H}_{10}\text{O}$	Isobutyl alcohol.....	-0.798	(81)
$\text{C}_2\text{H}_4\text{O}_2$	Acetic acid.....	-0.526	(81)	$\text{C}_4\text{H}_{10}\text{O}$	<i>tert</i> -Butyl alcohol.....	-0.800	(81)
$\text{C}_2\text{H}_4\text{Br}$	Methyl formate.....	-0.518	(82)	$\text{C}_4\text{H}_{10}\text{O}$	Ethyl ether.....	-0.766	(71)
$\text{C}_2\text{H}_4\text{I}$	Ethyl bromide.....	-0.489	(81)	$\text{C}_4\text{H}_{10}\text{OS}$	Ethyl sulfine.....	-0.631	(84)
$\text{C}_2\text{H}_4\text{NO}$	Ethyl iodide.....	-0.679	(71)	$\text{C}_4\text{H}_{10}\text{O}_2\text{S}$	Ethyl sulfite.....	-0.546	(84)
$\text{C}_2\text{H}_4\text{NO}_2$	Acetamide.....	-0.577	(82)	$\text{C}_4\text{H}_{10}\text{O}_2\text{S}$	Ethylsulfone ethyl ether.....	-0.592	(84)
$\text{C}_2\text{H}_5\text{O}$	Nitroethane.....	-0.472	(82)	$\text{C}_4\text{H}_{10}\text{O}_2\text{S}$	Diethyl sulfate.....	-0.563	(84)
$\text{C}_2\text{H}_5\text{O}$	Ethyl alcohol.....	-0.744	(81)	$\text{C}_4\text{H}_{10}\text{S}$	Diethyl sulfide.....	-0.753	(81)
$\text{C}_2\text{H}_5\text{O}_2$	Methyl ether.....	-0.716	(81)	$\text{C}_4\text{H}_{11}\text{N}$	Diethylamine.....	-0.835	(81, 82)
$\text{C}_2\text{H}_5\text{O}_2\text{S}$	Glycol.....	-0.624	(82)	$\text{C}_4\text{H}_{11}\text{N}$	Isobutylamine.....	-0.843	(81)
$\text{C}_2\text{H}_5\text{S}$	Dimethyl sulfate.....	-0.493	(81)	$\text{C}_4\text{H}_{11}\text{As}_2$	Cacodyl.....	-0.476	(84)
$\text{C}_2\text{H}_7\text{AsO}_2$	Dimethyl sulfide.....	-0.723	(81)	$\text{C}_4\text{H}_4\text{O}_2$	Furfural.....	-0.492	(82)
$\text{C}_2\text{H}_7\text{NO}$	Cacodylic acid.....	-0.579	(84)	$\text{C}_4\text{H}_5\text{N}$	Pyridine.....	-0.623	(82)
	Ethylhydroxylamine.....	-0.704	(82)	$\text{C}_4\text{H}_7\text{NO}_2$	Ethyl cyanoacetate.....	-0.595	(81)



TABLE 4.—(Continued)

Formula	Name (and temperature)	$\chi$	Lit.	Formula	Name (and temperature)	$\chi$	Lit.
$C_5H_8O_2$	Acetylacetone.....	-0.561	(82)	$C_6H_{10}O_2$	Diethanolacetylene.....	-0.660	(82)
$C_5H_8O_2$	Allyl acetate.....	-0.566	(81)	$C_6H_{10}O_2$	Dimethylketotetrahydrofur-		
$C_5H_8O_4$	Dimethyl malonate.....	-0.520	(82)		furane.....	-0.600	(82)
$C_5H_{10}$	Isoamylene.....	-0.766	(71)	$C_6H_{10}O_2$	Methylacetylacetone.....	-0.569	(82)
$C_5H_{10}$	Trimethylethylene.....	-0.773	(81)	$C_6H_{10}O_2$	Ethyl acetoacetate (old)	-0.556	(81)
$C_5H_{10}Br_2$	Amylene bromide.....	-0.498	(81)		(fresh).....	-0.576	(81)
$C_5H_{10}Cl_2$	Amylene chloride.....	-0.675	(81)	$C_6H_{10}O_4$	Diethyl oxalate.....	-0.555	(82)
$C_5H_{10}Cl_2$	Amylidene chloride.....	-0.662	(81)	$C_6H_{12}$	Hexene.....	-0.780	(85)
$C_5H_{10}N_2O$	Nitrosopiperidine.....	-0.555	(82)	$C_6H_{12}$	Cyclohexane.....	-0.810	(85)
$C_5H_{10}O$	Isovaleraldehyde.....	-0.668	(82)	$C_6H_{12}O$	Methyl butyl ketone.....	-0.690	(82)
$C_5H_{10}O$	Methyl propyl ketone.....	-0.668	(82)	$C_6H_{12}O$	Methyl isobutyl ketone.....	-0.697	(81)
$C_5H_{10}O_2$	Isovaleric acid.....	-0.663	(81)	$C_6H_{12}O$	Methyl <i>tert.</i> -butyl ketone.....	-0.703	(81)
$C_5H_{10}O_2$	Ethyl lactate.....	-0.615	(82)	$C_6H_{12}O$	Cyclohexanol.....	-0.727	(85)
$C_5H_{11}Br$	Isoamyl bromide.....	-0.587	(81)	$C_6H_{12}O_2$	Isobutyl acetate.....	-0.680	(81)
$C_5H_{11}Cl$	Isoamyl chloride.....	-0.741	(81)	$C_6H_{12}O_2$	Methyl $\alpha$ -methoxyisobutyrate..	-0.620	(82)
$C_5H_{11}N$	Piperidine.....	-0.755	(81)	$C_6H_{12}O_2$	Paraldehyde.....	-0.652	(81)
$C_5H_{11}NO_2$	Amyl nitrate.....	-0.574	(81)	$C_6H_{14}$	Hexane.....	-0.888	(81)
$C_5H_{12}O$	<i>n</i> -Amyl alcohol.....	-0.766	(71)	$C_6H_{14}O$	Hexyl alcohol.....	-0.766	(71)
$C_5H_{12}O$	Isoamyl alcohol.....	-0.799	(81)	$C_6H_{14}S$	Propyl sulfide.....	-0.777	(81)
$C_5H_{12}O$	<i>tert.</i> -Amyl alcohol.....	-0.804	(81)	$C_6H_{14}OP$	Triethylphosphine oxide.....	-0.683	(84)
$C_5H_{12}O_2$	Acetal.....	-0.825	(82)	$C_6H_{14}O_3P$	Triethyl phosphite.....	-0.631	(84)
$C_5H_{13}N$	Isoamylamine.....	-0.848	(81)	$C_6H_{14}O_4P$	Triethyl phosphate.....	-0.688	(84)
$C_6Cl_4O_2$	Chloranil.....	-0.458	(82)	$C_6H_{14}P$	Triethylphosphine.....	-0.762	(84)
$C_6Cl_6$	Hexachlorobenzene.....	-0.518	(82)	$C_7H_4F_3NO_2$	Nitrophenylfluoroform.....	-0.440	(82)
$C_6O_4.8H_2O$	Triquinoyl.....	-0.426	(82)	$C_7H_4ClO$	Benzoyl chloride (20°).....	-0.539	(80)
$C_6HBr_5O$	Pentabromophenol.....	-0.397	(82)		(-20°).....	-0.561	(80)
$C_6H_2Cl_6O_2$	Hexachlorohexanetrione.....	-0.433	(82)	$C_7H_5F_3$	Phenylfluoroform.....	-0.529	(82)
$C_6H_2Br_2NO_2$	Dibromo-4-nitrophenol.....	-0.564	(82)	$C_7H_5F_3O$	Trifluorocresol.....	-0.517	(82)
$C_6H_2Cl_2$	Trichlorobenzene.....	-0.587	(81)	$C_7H_5N$	Phenyl cyanide.....	-0.651	(81)
$C_6H_2N_3O_6$	1, 3, 5-Trinitrobenzene.....	-0.352	(82)	$C_7H_5NO$	Phenyl isocyanate.....	-0.610	(85)
$C_6H_2N_2O_4$	<i>m</i> -Dinitrobenzene.....	-0.398	(82)	$C_7H_5Cl_2$	Benzal chloride.....	-0.608	(82)
$C_6H_2N_2O_4$	2, 4-Dinitrophenol.....	-0.397	(82)	$C_7H_5O$	Benzaldehyde.....	-0.573	(81)
$C_6H_2N_2O_4$	Dinitroresorcinol.....	-0.312	(82)	$C_7H_5O_2$	Benzoic acid.....	-0.556	(45, 46)
$C_6H_4O_2$	Quinone.....	-0.382	(82)	$C_7H_7Cl$	Benzyl chloride (-60°).....	-0.661	(80)
$C_6H_5Br$	Bromobenzene (-30°).....	-0.514	(80)		(-30°).....	-0.695	(80)
	(-20°).....	-0.540	(80)	$C_7H_7NO$	Benzamide.....	-0.597	(82)
$C_6H_5Cl$	Chlorobenzene.....	-0.639	(81)	$C_7H_7NO$	Benzaldoxime.....	-0.576	(82)
	(-50°).....	-0.629	(80)	$C_7H_7NO_2$	<i>o</i> -Nitrotoluene.....	-0.532	(82)
	(-30°).....	-0.664	(80)	$C_7H_8$	Toluene.....	-0.729	(81)
$C_6H_5Cl_2O_2$	Pentachlorohexanedione.....	-0.452	(82)	$C_7H_8O$	Benzyl alcohol.....	-0.705	(81)
$C_6H_5F$	Fluorobenzene.....	-0.608	(82)	$C_7H_8O$	Anisole.....	-0.672	(81)
$C_6H_5I$	Iodobenzene.....	-0.471	(81)	$C_7H_8O_2$	Guaiacol.....	-0.638	(81)
$C_6H_5NO$	Nitrosobenzene.....	-0.514	(82)	$C_7H_8N$	Methylaniline.....	-0.713	(81)
$C_6H_5NO_2$	Nitrobenzene (-160°).....	-0.455	(80)	$C_7H_8N$	<i>o</i> -Toluidine.....	-0.701	(81)
	(0°).....	-0.439	(80)	$C_7H_8NO$	Anisidine.....	-0.654	(81)
	(20°).....	-0.499	(80)	$C_7H_{12}$	1-Heptene.....	-0.807	(82)
$C_6H_5NO_2$	Quinonoxime.....	-0.409	(82)	$C_7H_{12}$	2-Heptene.....	-0.786	(82)
$C_6H_5NO_2$	<i>p</i> -Nitrophenol.....	-0.482	(82)	$C_7H_{12}O$	2-Methylcyclohexanone.....	-0.660	(82)
$C_6H_6$	Benzene (16.8°).....	-0.712	(55, 56)	$C_7H_{12}O$	3-Methylcyclohexanone.....	-0.667	(82)
$C_6H_6O$	Phenol.....	-0.648	(81)	$C_7H_{12}O$	4-Methylcyclohexanone.....	-0.566	(82)
$C_6H_6O_2$	Resorcinol.....	-0.617	(82)	$C_7H_{12}O_2$	Hexahydrobenzoic acid.....	-0.649	(85)
$C_6H_6O_2$	Phloroglucinol.....	-0.582	(82)	$C_7H_{12}O_2$	Ethyl 1-methylacetoacetate.....	-0.590	(81)
$C_6H_7N$	Aniline (-10°).....	-0.661	(80)	$C_7H_{12}O_2$	Diethyl malonate.....	-0.585	(82)
	(10°).....	-0.692	(80)	$C_7H_{14}Cl_2$	Oenanthylidene chloride.....	-0.689	(81)
$C_6H_7NO$	Phenylhydroxylamine.....	-0.625	(82)	$C_7H_{14}O$	Heptaldehyde.....	-0.714	(81)
$C_6H_8$	1, 3-Cyclohexadiene.....	-0.607	(85)	$C_7H_{14}O_2$	Ethyl isovalerate.....	-0.700	(81)
$C_6H_8$	1, 4-Cyclohexadiene.....	-0.608	(85)	$C_8H_4I$	1-Iodo-2-phenylacetylene.....	-0.483	(82)
$C_6H_8N_2$	Phenylhydrazine (20°).....	-0.675	(80)	$C_8H_4NO_2$	Phthalimide.....	-0.533	(82)
	(10°).....	-0.720	(80)	$C_8H_6$	Phenylacetylene.....	-0.673	(82)
$C_6H_8BiO_4$	Bismuth acetate.....	-0.090	(44)	$C_8H_6O_4$	Phthalic acid.....	-0.446	(45, 46)
$C_6H_8NO_2$	Ethylsuccinimide.....	-0.566	(82)	$C_8H_7N$	Benzyl cyanide.....	-0.676	(81)
$C_6H_{10}$	Cyclohexene.....	-0.711	(85)	$C_8H_8$	Styrene.....	-0.655	(82)
$C_6H_{10}$	Diallyl.....	-0.671	(81)	$C_8H_8N_2O_2$	Phthalamide.....	-0.556	(82)
$C_6H_{10}O$	Cyclohexenol.....	-0.653	(85)	$C_8H_8O$	Acetophenone (15°).....	-0.597	(80)
$C_6H_{10}O$	Cyclohexanone.....	-0.648	(82)		(25°).....	-0.621	(80)



TABLE 4.—(Continued)

Formula	Name (and temperature)	$\chi$	Lit.	Formula	Name (and temperature)	$\chi$	Lit.
$C_6H_5O_2$	Anisaldehyde.....	-0.568	(82)	$C_{10}H_{18}O$	Eucalyptol.....	-0.754	(81)
$C_6H_5O_2$	Methyl benzoate.....	-0.602	(81)	$C_{10}H_{18}O$	Dimethyldiethylketotetrahydro-		
$C_6H_5O_2$	Methyl salicylate.....	-0.580	(81)		furfurane.....	-0.753	(82)
$C_6H_5FO$	<i>p</i> -Fluorophenetole.....	-0.628	(82)	$C_{10}H_{18}O_2$	Diisobutyralacetylene.....	-0.738	(82)
$C_6H_5N$	Benzylidenemethylamine.....	-0.613	(82)	$C_{10}H_{18}O_3$	Ethyl 1-isobutylacetoacetate...	-0.652	(81)
$C_6H_{10}$	<i>o</i> -Xylene (-40°).....	-0.728	(80)	$C_{10}H_{21}N$	Diethylcyclohexylamine.....	-0.802	(81)
	(-10°).....	-0.662	(80)	$C_{10}H_{22}$	Decane.....	-0.876	(81)
$C_6H_{10}$	<i>m</i> -Xylene.....	-0.743	(81)	$C_{10}H_{22}O$	Isoamyl ether.....	-0.813	(82)
$C_6H_{10}O$	Phenetole.....	-0.692	(81)	$C_{10}H_{23}N$	Diisoamylamine.....	-0.846	(82)
$C_6H_{11}N$	Dimethylaniline.....	-0.711	(81)	$C_{11}H_9NO_4$	Ethyl nitrophenylpropiolate.....	-0.502	(82)
$C_6H_{11}N$	Ethylaniline.....	-0.709	(81)	$C_{11}H_{10}Br_2O_2$	Ethyl dibromocinnamate.....	-0.498	(82)
$C_6H_{12}Br_2$	2, 5-Dimethyl-2, 5-dibromo-3-			$C_{11}H_{10}O$	Propionylphenylacetylene.....	-0.601	(82)
	hexine.....	-0.506	(82)	$C_{11}H_{10}O_2$	Ethyl phenylpropiolate.....	-0.598	(82)
$C_6H_{14}$	2, 4-Dimethyl-2, 4-hexadiene...	-0.714	(85)	$C_{11}H_{12}O_2$	Ethyl cinnamate.....	-0.610	(82)
$C_6H_{14}O$	Dimethylcyclohexanone.....	-0.672	(82)	$C_{11}H_{12}O_3$	Ethyl benzoylacetate.....	-0.600	(81)
$C_6H_{14}O_2$	Tetramethylketotetrahydrofur-			$C_{11}H_{18}$	Dimethyl-2, 4-nonatriene.....	-0.990	(85)
	furane.....	-0.736	(82)	$C_{11}H_{18}$	2, 6-Dimethyl-2, 6, 8-nonatriene	-0.724	(82)
$C_6H_{14}O_2$	2, 5-Dimethyl-3-hexin-2, 5-diol	-0.724	(82)	$C_{11}H_{18}O_2$	Ethyl hexylpropiolate.....	-0.684	(82)
$C_6H_{14}O_2$	Tetrolic acetal.....	-0.688	(82)	$C_{11}H_{18}O_2$	Geraniol formate.....	-0.658	(81)
$C_6H_{14}O_3$	Ethyl 1-ethylacetoacetate.....	-0.615	(81)	$C_{12}H_{10}$	Diphenyl.....	-0.677	(82)
$C_6H_{14}O_4$	Diethyl succinate.....	-0.604	(82)	$C_{12}H_{10}AsCl$	Diphenylchloroarsine.....	-0.550	(84)
$C_6H_{14}O_6$	Diethyl tartrate.....	-0.550	(82)	$C_{12}H_{10}N_2$	Azobenzene.....	-0.612	(82)
$C_6H_{16}$	Octylene.....	-0.798	(81)	$C_{12}H_{10}N_2O$	Hydroxyazobenzene.....	-0.503	(81)
$C_6H_{16}Br_2$	Octylene bromide.....	-0.553	(81)	$C_{12}H_{10}O$	Diphenyl ether.....	-0.635	(82)
$C_6H_{16}N_2$	Isobutylideneazine.....	-0.683	(82)	$C_{12}H_{10}O_2S$	Phenylsulfone.....	-0.591	(84)
$C_6H_{16}O$	Methyl hexyl ketone.....	-0.728	(82)	$C_{12}H_{11}N$	Diphenylamine.....	-0.634	(82)
$C_6H_{17}Cl$	Octyl chloride.....	-0.773	(81)	$C_{12}H_{11}NO_2$	Ethyl benzylidenecyanoacetate	-0.578	(82)
$C_6H_{17}NO$	Octanonoxime.....	-0.717	(82)	$C_{12}H_{11}N_3$	Aminoazobenzene.....	-0.600	(82)
$C_6H_{18}$	Octane.....	-0.872	(81)	$C_{12}H_{12}N_4$	Chrysoidine.....	-0.595	(81)
$C_6H_{18}O$	Octyl alcohol.....	-0.806	(81)	$C_{12}H_{12}O$	Butyrylphenylacetylene.....	-0.618	(82)
$C_6H_{18}N$	Diisobutylamine.....	-0.848	(81)	$C_{12}H_{14}As_2Cl_7$			
$C_6H_{17}N$	Quinoline.....	-0.662	(81)	$N_2O_2 \cdot 2H_2O$	Salvarsan dihydrochloride.....	-0.518	(84)
$C_6H_7NO$	Phenylpropiolamide.....	-0.574	(82)	$C_{12}H_{16}N_3O_6$	Triethyl triazinetricarbonate...	-0.552	(85)
$C_6H_8$	Indene.....	-0.730	(82)	$C_{12}H_{20}O_2$	Propyl hexylpropiolate.....	-0.697	(82)
$C_6H_8O$	Cinnamic aldehyde.....	-0.566	(82)	$C_{12}H_{20}O_7$	Triethyl citrate.....	-0.586	(81)
$C_6H_{10}$	$\alpha$ -Methylstyrene.....	-0.678	(82)	$C_{13}H_{22}$	Dicyclohexyl.....	-0.774	(82)
$C_6H_{10}$	Hydrindene.....	-0.664	(82)	$C_{13}H_{22}O_4$	Diacetal.....	-0.668	(82)
$C_6H_{10}O$	Cinnamyl alcohol.....	-0.650	(82)	$C_{13}H_{27}N$	Triisobutylamine.....	-0.846	(81)
$C_6H_{10}O_3$	Ethyl benzoate.....	-0.628	(81)	$C_{13}H_8O_2$	Xanthone.....	-0.551	(82)
$C_6H_{11}N$	Tetrahydroquinoline.....	-0.668	(82)	$C_{13}H_9N$	Acridine.....	-0.688	(82)
$C_6H_{11}Br$	Hexylpropiolamide.....	-0.677	(82)	$C_{13}H_{10}$	Fluorene.....	-0.665	(82)
$C_{10}H_7NO_2$	Bromonaphthalene.....	-0.598	(81)	$C_{13}H_{10}O$	Benzophenone.....	-0.594	(82)
$C_{10}H_8$	$\alpha$ -Nitronaphthalene.....	-0.564	(82)	$C_{13}H_{11}N$	Benzylidenedianiline.....	-0.554	(82)
$C_{10}H_8O$	Naphthalene.....	-0.717	(82)	$C_{13}H_{12}$	Diphenylmethane.....	-0.685	(82)
$C_{10}H_8O$	Naphthol.....	-0.673	(82)	$C_{13}H_{12}N_2O$	<i>p</i> -Methoxyazobenzene.....	-0.560	(82)
$C_{10}H_8O_2$	Acetylphenylacetylene.....	-0.731	(82)	$C_{13}H_{13}O_2P$	Methyldiphenoxyphosphine		
$C_{10}H_{10}$	Methyl phenylpropiolate.....	-0.573	(82)		oxide.....	-0.616	(84)
$C_{10}H_{10}$	Phenylbutadiene.....	-0.658	(82)	$C_{13}H_{14}O$	Valerylphenylacetylene.....	-0.639	(82)
$C_{10}H_{10}O_2$	Dihydronaphthalene.....	-0.654	(82)	$C_{14}H_8O_2$	Anthraquinone.....	-0.575	(82)
$C_{10}H_{10}O_2$	Benzoylacetone.....	-0.586	(82)	$C_{14}H_8O_2$	Phenanthraquinone.....	-0.509	(82)
$C_{10}H_{12}$	Safrol and isosafrol.....	-0.601	(81)	$C_{14}H_{10}$	Anthracene.....	-0.726	(82)
$C_{10}H_{12}O$	$\alpha, \omega$ -Dimethylstyrene.....	-0.686	(82)	$C_{14}H_{10}$	Phenanthrene.....	-0.718	(82)
$C_{10}H_{12}O_2$	Anethole.....	-0.648	(82)	$C_{14}H_{10}$	Tolane.....	-0.667	(82)
$C_{10}H_{14}$	Eugenol and isoeugenol.....	-0.622	(81)	$C_{14}H_{10}O_3$	Benzoic anhydride.....	-0.552	(45, 46)
$C_{10}H_{14}O$	Cymene.....	-0.769	(81)	$C_{14}H_{12}$	1, 1-Diphenylethylene.....	-0.655	(82)
$C_{10}H_{14}O$	Carvone.....	-0.614	(82)	$C_{14}H_{12}$	Stilbene.....	-0.666	(82)
$C_{10}H_{14}O_2$	Carvacrol.....	-0.726	(82)	$C_{14}H_{12}N_2$	Benzalazine.....	-0.594	(82)
$C_{10}H_{14}O_2$	Camphoric anhydride.....	-0.620	(45, 46)	$C_{14}H_{14}N_2$	Azotoluene.....	-0.643	(82)
$C_{10}H_{14}O_2$	Camphor.....	-0.68	(35)	$C_{14}H_{14}N_2O_2$	<i>p</i> -Azoanisole.....	-0.610	(81)
$C_{10}H_{14}O_2$	Citral.....	-0.650	(81)	$C_{14}H_{15}N$	Methylbenzylaniline.....	-0.670	(81)
$C_{10}H_{14}O_4$	Ethyl amylpropiolate.....	-0.670	(82)	$C_{14}H_{15}N_2$	Aminoazotoluene.....	-0.631	(81)
$C_{10}H_{16}O$	Camphoric acid.....	-0.746	(45, 46)	$C_{14}H_{16}O$	Caproylphenylacetylene.....	-0.651	(82)
$C_{10}H_{16}O$	Terpineol.....	-0.725	(85)	$C_{14}H_{22}O_2$	Dicyclohexanolacetylene.....	-0.682	(82)



TABLE 4.—(Continued)

Formula	Name (and temperature)	$\chi$	Lit.
$C_{14}H_{26}O_4$	Diethyl sebacate.....	-0.685	(82)
$C_{16}H_{18}N$	Cinnamylideneaniline.....	-0.595	(82)
$C_{16}H_{32}N$	Triisoamylamine.....	-0.845	(81)
$C_{16}H_{19}$	Diphenyldiacetylene.....	-0.640	(82)
$C_{16}H_{12}N_2O$	Benzeneazo- $\beta$ -naphthol.....	-0.567	(81)
$C_{16}H_{12}N_2$	Methyldiphenyltriazine.....	-0.627	(85)
$C_{16}H_{18}N_2O_2$	<i>p</i> -Azophenetole.....	-0.635	(81)
$C_{17}H_{14}O$	1-Phenyl-4-benzoyl-1, 3-buta- diene.....	-0.599	(82)
$C_{18}H_{12}$	Chrysene.....	-0.648	(82)
$C_{18}H_{15}As$	Triphenylarsine.....	-0.578	(84)
$C_{18}H_{15}AsO$	Diphenylphenoxyarsine.....	-0.567	(84)
$C_{18}H_{15}AsO$	Triphenylarsine oxide.....	-0.618	(84)
$C_{18}H_{15}AsO_3$	Triphenoxyarsine.....	-0.551	(84)
$C_{18}H_{16}Bi$	Triphenylbismuthine.....	-0.447	(84)
$C_{18}H_{15}BiN_2O_6$	Triphenylbismuthine dinitrate.....	-0.451	(84)
$C_{18}H_{15}O_3P$	Triphenyl phosphite.....	-0.592	(84)
$C_{18}H_{15}P$	Triphenylphosphine.....	-0.636	(84)
$C_{18}H_{15}Sb$	Triphenylstibine.....	-0.516	(84)
$C_{18}H_{17}AsO_2$	Triphenylarsine dihydroxide.....	-0.795	(84)
$C_{18}H_{17}O_2Sb$	Triphenylstibine dihydroxide.....	-0.616	(84)
$C_{18}H_{18}N_3OP$	Trianilinophosphine oxide.....	-0.624	(84)
$C_{18}H_{34}O_2$	Oleic acid.....	-0.742	(81)
$C_{19}H_{14}O_3$	Aurin.....	-0.556	(81)
$C_{19}H_{16}$	Triphenylmethane.....	-0.674	(82)
$C_{19}H_{16}O$	Triphenyl carbinol.....	-0.675	(82)

TABLE 5.—SPECIFIC SUSCEPTIBILITY ( $\chi$ ): CRYSTALS

$\chi_1$ ,  $\chi_2$ ,  $\chi_3$  are the three principal values;  $\Psi$  = angle between the crystallographic *c* axis and a principal axis of magnetization; room temperature; unit of  $\chi$  =  $10^{-6}$  cgsu.

Substance	$\chi_1$	$\chi_2$	$\chi_3$	$\Psi$	Lit.
$Al_2O_3$ .....	Corundum	-0.34	M		(127)
$Al_2O_3$ .....	Ruby	0.47			(127)
$(AlF)_2SiO_4^*$ .....	Topaz	-0.410	-0.420	-0.420	(112)
$H_2Al_2(BOH)_2Si_2O_{11}^\dagger$ .....	Tourmaline	1.12		0.748	(112)
$Be_2Al_2(SiO_3)_4$ .....	Beryl	0.826		0.386	(112)
$C^\ddagger$ .....	Graphite	-2.2		-14.2	(53)
$C_{12}H_{22}O_{11}$ .....	Cane sugar	-0.60	-0.55	-0.57	-1° 50' (34)
$CaF_2$ .....	Fluorite	-0.285			(85)
$Ca_3Cl(PO_4)_3$ .....	Apatite	-2.64		-2.64	(112)
$CaCO_3$ .....	Aragonite	-0.392	-0.387	-0.444	(112)
$CaCO_3$ .....	Calcite	-0.363		-0.405	(112)
$HCa_2(Al, Fe)_2Si_2O_{13}^*$ .....	Epidote	23.8	24.1	23.9	(34)
$CaMgCrO_4$ .....	Dolomite	0.787		1.20	(112)
$(Ca, Mg, Fe)_2Si_2O_7^*$ .....	Hornblende	24.0	16.7	18.0	-21° 55' (34)
$CaMgSiO_4^\ddagger$ .....	Augite	26.6	12.8	22.7	-7° 0' (34)
$CoSO_4 \cdot 7H_2O$ .....		36.3	32.7	35.0	-39° 40' (34)
$Co(NH_4)_2(SO_4)_2 \cdot 6H_2O$ .....		26.1	21.9	25.5	-31° 18' (87)
$CoCu(SO_4)_2 \cdot 6H_2O$ .....		28.6	23.1	25.6	-52° 54' (34)
$CuSiO_3 \cdot H_2$ .....	Diopside	8.8	M		(38)
$CuFeS_2$ .....	Chalcopyrite			(See FeCuS <sub>2</sub> )	
$FeS_2$ .....	Pyrite	0.98			(127)
$FeSO_4 \cdot 7H_2O$ .....		44.3	41.1	40.2	30° 10' (34)
$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ .....		46.2	40.9	40.5	-18° 58' (34)
$FeCO_3$ .....	Siderite	84.2		142.6	(38)
$FeCuS_2$ .....	Chalcopyrite	0.85	M		(65)
$(Fe, Zn, Mn)_2O_3 \cdot (Fe, Mn)_2O_3^*$ .....	Franklinite	455 to 640			(127)
$K_2Co(SO_4)_2 \cdot 6H_2O$ .....		30.2	22.4	35.0	-21° 20' (127)
$KAlSi_3O_8$ .....	Adularia	-0.427	-0.384	-0.317	-13° 20' (34)
$MgAl_2O_4$ .....	Spinel	0.62			(127)
$NaCl$ .....	Rock salt	-0.50			(65)
$NiSO_4 \cdot 7H_2O$ .....		16.66	16.53	16.63	(57)
$Ni(NH_4)_2(SO_4)_2 \cdot 6H_2O$ .....		10.2	8.23	9.38	-16° 17' (34)
$PbS$ .....	Galena	-0.350			(112)
$SiO_2$ .....	Quartz	-0.461	-0.466	(cf. p. 341.)	(112)
$SrSO_4$ .....	Celestine	-0.342	-0.314	-0.359	(112)

TABLE 5.—(Continued)

Substance	$\chi_1$	$\chi_2$	$\chi_3$	$\Psi$	Lit.
$TiO_2$ .....	Rutile	1.96		2.09	(112)
$ZnS$ .....	Sphalerite	-0.264			(112)
$ZrSiO_4$ .....	Zircon	-0.170		+0.732	(112)

\* Composition variable. † H may be replaced by Mg, Fe, or alkalies. ‡ Ceylon. § With addition of (Mg, Fe)(Al, Fe)<sub>2</sub>SiO<sub>4</sub>.

TABLE 6.—SPECIFIC SUSCEPTIBILITY ( $\chi$ ): MISCELLANEOUS SUBSTANCESUnit of  $\chi$  =  $10^{-6}$  cgsu

Substance	$\chi$	Lit.	Substance	$\chi$	Lit.
Air; * 20°C, 1 atm..	24.16g	M	Glass, crown†.....	-0.90	(62, 63)
	24.40g	(20)	heavy flint.....	-1.2	
	23.85g	(100)	Linseed oil.....	-0.74	(35)
	24.40g	(122)	Marble; CaCO <sub>3</sub> .....	-0.8	(128)
	24.00g	(10)	Paraffin.....	-0.6	(128)
Celluloid.....	-0.13	(62, 63)	Petroleum.....	-0.83	(71)
Colza oil.....	-0.79	(93)	Shellac.....	-0.30	(71)
Cumene.....	-0.74	(71)	Terpene.....	-0.67	(71)
Ebonite.....	0.6	(125)	Wax, white.....	-0.6	(125)
Gypsum; CaSO <sub>4</sub> ·2H <sub>2</sub> O.....	-0.86	(62, 63)	Wood.....	-0.3 to 0.7	(125)

\* For  $\chi$ , see Table 1. † Borosilicate.

TABLE 7.—SPECIFIC SUSCEPTIBILITY OF SOLUTIONS: REFERENCES

The solvent is stated at the beginning of each section

Solute	Lit.	Solute	Lit.
<b>H<sub>2</sub>O</b>		<b>H<sub>2</sub>O.—(Continued)</b>	
BaI <sub>2</sub> .....	(62, 63)	MnCl <sub>2</sub> .....	(12.1, 92)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> , Acetic acid.....	(99)	MnBr <sub>2</sub> .....	(65)
C <sub>3</sub> H <sub>8</sub> O, Acetone.....	(99)	MnI <sub>2</sub> .....	(65)
CeBr <sub>3</sub> .....	(27)	MnSO <sub>4</sub> .....	(14)
CoF <sub>2</sub> .....	(65)	Mn(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O.....	(12.1, 92)
CoCl <sub>2</sub> .....	(92)	MnPO <sub>4</sub> .....	(117)
CoBr <sub>2</sub> .....	(33)	NiF <sub>2</sub> .....	(65)
CoI <sub>2</sub> .....	(65)	NiCl <sub>2</sub> .....	(119)
CoSO <sub>4</sub> .....	(16)	NiBr <sub>2</sub> .....	(65)
Co(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O.....	(92)	NiSO <sub>4</sub> .....	(119)
CoSO <sub>4</sub> ·(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> .....	(93)	Ni(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O.....	(12.1, 119)
Cr(OH) <sub>3</sub> .....	(92)	PtCl <sub>4</sub> .....	(62)
CrCl <sub>3</sub> .....	(117); cf. (15)	YbCl <sub>3</sub> .....	(27)
Cr <sub>2</sub> Cl <sub>4</sub> O*†.....	(15)	ZnCl <sub>2</sub> .....	(62)
CrSO <sub>4</sub> .....	(15)	<b>CH<sub>3</sub>OH, Methyl alcohol</b>	
Cr <sub>2</sub> O(SO <sub>4</sub> ) <sub>2</sub> †  .....	(15)	CoCl <sub>2</sub> .....	(92)
Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> *†§.....	(14)	FeCl <sub>3</sub> .....	(92)
Cr(NO <sub>3</sub> ) <sub>3</sub> ·9H <sub>2</sub> O.....	(92)	MnCl <sub>2</sub> .....	(92)
CuCl <sub>2</sub>   .....	(59)	Mn(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O.....	(92)
CuBr <sub>2</sub> .....	(59)	<b>C<sub>2</sub>H<sub>5</sub>OH, Ethyl alcohol</b>	
CuSO <sub>4</sub> †  .....	(59)	CoCl <sub>2</sub> .....	(92)
Cu(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O  .....	(59)	CuCl <sub>2</sub>   .....	(59)
CuC <sub>4</sub> H <sub>6</sub> O <sub>4</sub> ·H <sub>2</sub> O**.....	(92)	FeCl <sub>3</sub> †.....	(92)
ErCl <sub>3</sub> .....	(27)	MnCl <sub>2</sub> .....	(92)
FeCl <sub>2</sub> .....	(92)	Mn(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O.....	(92)
FeCl <sub>3</sub> ††.....	(13)	C <sub>2</sub> H <sub>5</sub> O, Acetone.....	(99)
FeBr <sub>3</sub> .....	(65)	<b>C<sub>2</sub>H<sub>5</sub>O<sub>2</sub>, Acetic acid</b>	
FeI <sub>2</sub> .....	(65)	FeCl <sub>3</sub> .....	(92)
FeSO <sub>4</sub>   .....	(121)	C <sub>2</sub> H <sub>6</sub> , Benzene.....	(99)
Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .....	(92)	<b>C<sub>2</sub>H<sub>5</sub>O, Acetone</b>	
Fe(NO <sub>3</sub> ) <sub>3</sub> ·6H <sub>2</sub> O††.....	(13)	CoCl <sub>2</sub> †.....	(92)
FeSO <sub>4</sub> ·(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> .....	(65)	FeCl <sub>3</sub> .....	(92)
KOH*.....	(62, 63)	Co(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O.....	(92)
K <sub>2</sub> Fe(CN) <sub>6</sub> .....	(45)	<b>C<sub>2</sub>H<sub>5</sub>O, Amyl alcohol</b>	
MgSO <sub>4</sub> .....	(103)	CoCl <sub>2</sub> .....	(92)
MnF <sub>2</sub> .....	(65)		

\* See also Table 3. † Also acidulated with HCl. ‡ Also in water + H<sub>2</sub>SO<sub>4</sub>. § Also in water + Na<sub>2</sub>SO<sub>4</sub>. || Also in water + C<sub>2</sub>H<sub>5</sub>OH. ¶ Also in water + NH<sub>3</sub>. \*\* Copper acetate. †† Also in aqueous solutions of HCl, of HNO<sub>3</sub>, of NaCl. For solutions in methyl, ethyl, isobutyl, allyl or isoamyl alcohol, or in formic acid, acetic acid, ethyl acetate, ethyl ether, or acetone, see (92). ‡‡ Also in water + HNO<sub>3</sub>.



TABLE 8.—SPECIFIC SUSCEPTIBILITY ( $\chi$ ): ALLOYS AND AMALGAMSUnit of  $\chi = 10^{-7}$  cgs

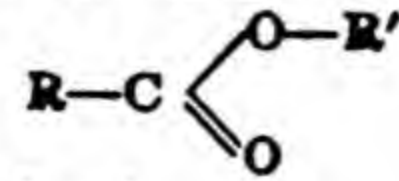
Alloy	Fig.	Lit.	Alloy	Fig.	Lit.
Ag-Sb.....	2	(28)	Cu-Ni.....	1	(40, 41, 42)
Al-Sb.....	2	(53)	Cu-Sb.....	3	(32)
Al-Zn.....	2	(28)	Cu-Sn.....	3	(32)
Bi-Cd.....	1	(44)	Cu-Zn.....	3	(32)
Bi-Hg.....	1	(44)	Pb-Sb.....	4	(32)
Bi-Pb.....	3	(32)	Pb-Sn.....	4	(53)
Bi-Sb.....	3	(53)	Pb-Tl.....	4	(32)
Bi-Sn.....	3	(32)	Sb-Sn.....	2	(32)
Bi-Te.....	1	(53)	Sb-Te.....	2	(32)
Bi-Tl.....	1	(70)	Sb-Zn.....	2	(53)
Bi-Zn.....	1	(32)	Sn-Te.....	4	(53)
Cd-Pb.....	4	(44)	Sn-Zn.....	3	(32)
Cu-Mn.....	3	(32)			

TABLE 9.—ATOMIC AND ATOMIC GROUP SUSCEPTIBILITIES ( $\chi_a$ )

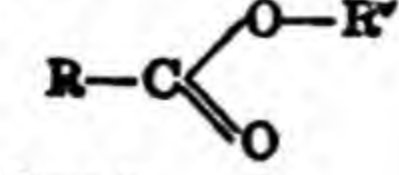
For many compounds, the molecular susceptibility is approximately equal to the sum of  $\chi_a$ 's for the several atomic groups which are contained in the compound; for certain organic groupings a correction ( $\lambda_m$ ) must be added to the sum of the  $\chi_a$ 's in order to obtain the value of the molecular susceptibility. Unit of  $\chi_a = 10^{-6}$  cgs per gram atom, or per gram atomic group; of  $\lambda_m = 10^{-6}$  cgs per gram molecule.

Atomic group	$\chi_a$	Atomic group	$\chi_a$	Atomic group	$\chi_a$
Ag <sup>+</sup>	-31.0	Sn <sup>++++</sup>	-30.3	Organic compounds	
Al <sup>+++</sup>	-13.1	Zn <sup>++</sup>	-13.5	C	-6.25
As <sup>+++</sup>	-20.9	Br <sup>-</sup>	-30.60	H	-3.05
As <sup>+++++</sup>	-43.0	Cl <sup>-</sup>	-20.10	N	-5.80
Au <sup>++</sup>	-45.8	F <sup>-</sup>	-6.30	S	-15.60
B <sup>+++</sup>	-7.3	I <sup>-</sup>	-44.60	O <sup>*</sup>	-4.61
Ba <sup>++</sup>	-38.2	NO <sub>2</sub> <sup>-</sup>	-14.2	O <sup>++</sup>	-3.36
Be <sup>++</sup>	-8.55	SO <sup>-</sup>	-13.4	O <sup>++</sup>	+1.73
Bi <sup>+++</sup>	-40.6	S <sub>2</sub> O <sub>3</sub> <sup>-</sup>	-43.4	$\lambda_m$ for	-1.50
Bi <sup>+++++</sup>	-69.8	S <sub>4</sub> O <sub>6</sub> <sup>-</sup>	-84.7	benzene	
Ca <sup>++</sup>	-15.9	SO <sub>2</sub> <sup>-</sup>	-17.9	bond	
Cd <sup>++</sup>	-20	SO <sub>3</sub> <sup>-</sup>	-24.7	$\lambda_m$ for one	-5.70
Ce <sup>+</sup>	-41.0	SO <sub>3</sub> <sup>-</sup>	-27.8	ethylene	
Cu <sup>+</sup>	-18.0	SO <sub>3</sub> <sup>-</sup>	-22.3	bond	
Hg <sup>++</sup>	-33.4	S <sub>2</sub> O <sub>4</sub> <sup>-</sup>	-56.0	$\lambda_m$ for two	-11.0
K <sup>+</sup>	-18.5	SO <sub>4</sub> <sup>-</sup>	-31.4	or more	
Li <sup>+</sup>	-4.2	SO <sub>4</sub> <sup>-</sup>	-33.6	ethylene	
Mg <sup>++</sup>	-10.1	CO <sub>3</sub> <sup>-</sup>	-22.2	bonds	
Na <sup>+</sup>	-9.2	PO <sup>-</sup>	-22.3		
P <sup>+++</sup>	-10.2	PO <sub>2</sub> <sup>-</sup>	-18.5		
Rb <sup>+</sup>	-27.2	PO <sub>3</sub> <sup>-</sup>	-23.8		
Sb <sup>+++</sup>	-26.1	PO <sub>3</sub> <sup>-</sup>	-31.3		
Sb <sup>+++++</sup>	-66.9	PO <sub>4</sub> <sup>-</sup>	-35.4		
Si <sup>+++</sup>	-20				
Si <sup>++++</sup>	-12.7				

\* —O— in R—O—R',



† O= in



‡ O= in

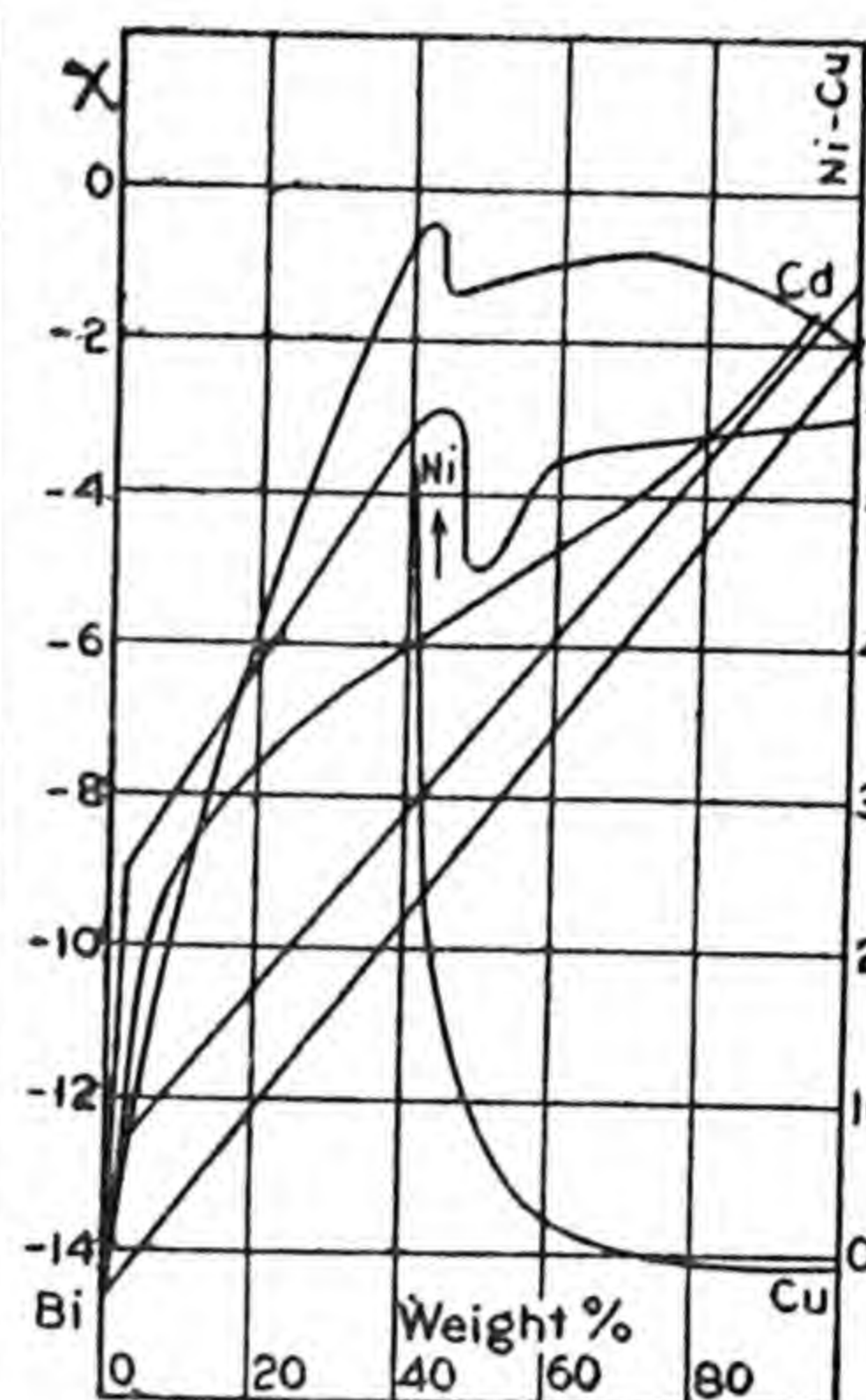
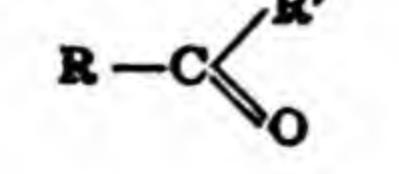


FIG. 1.

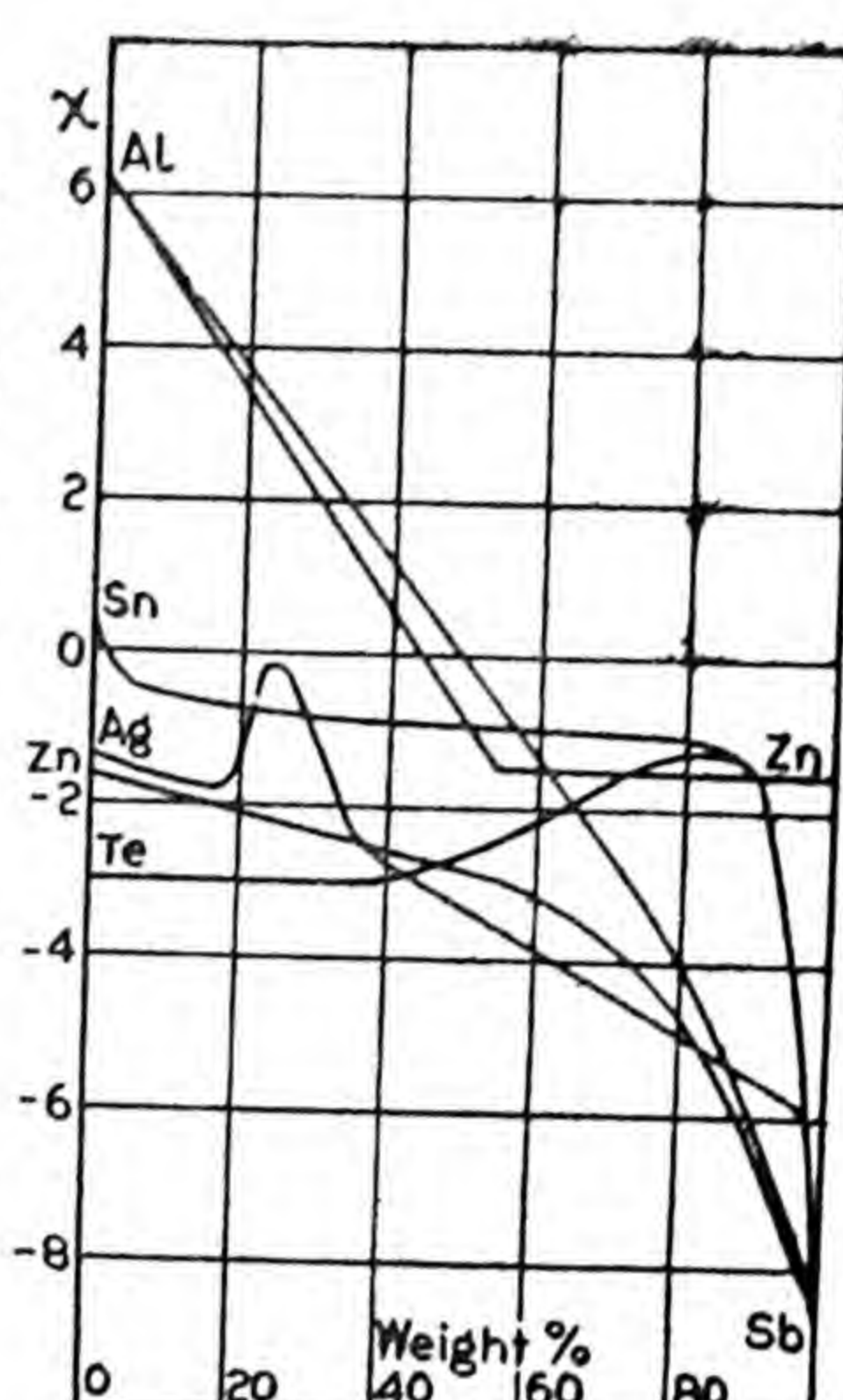


FIG. 2.

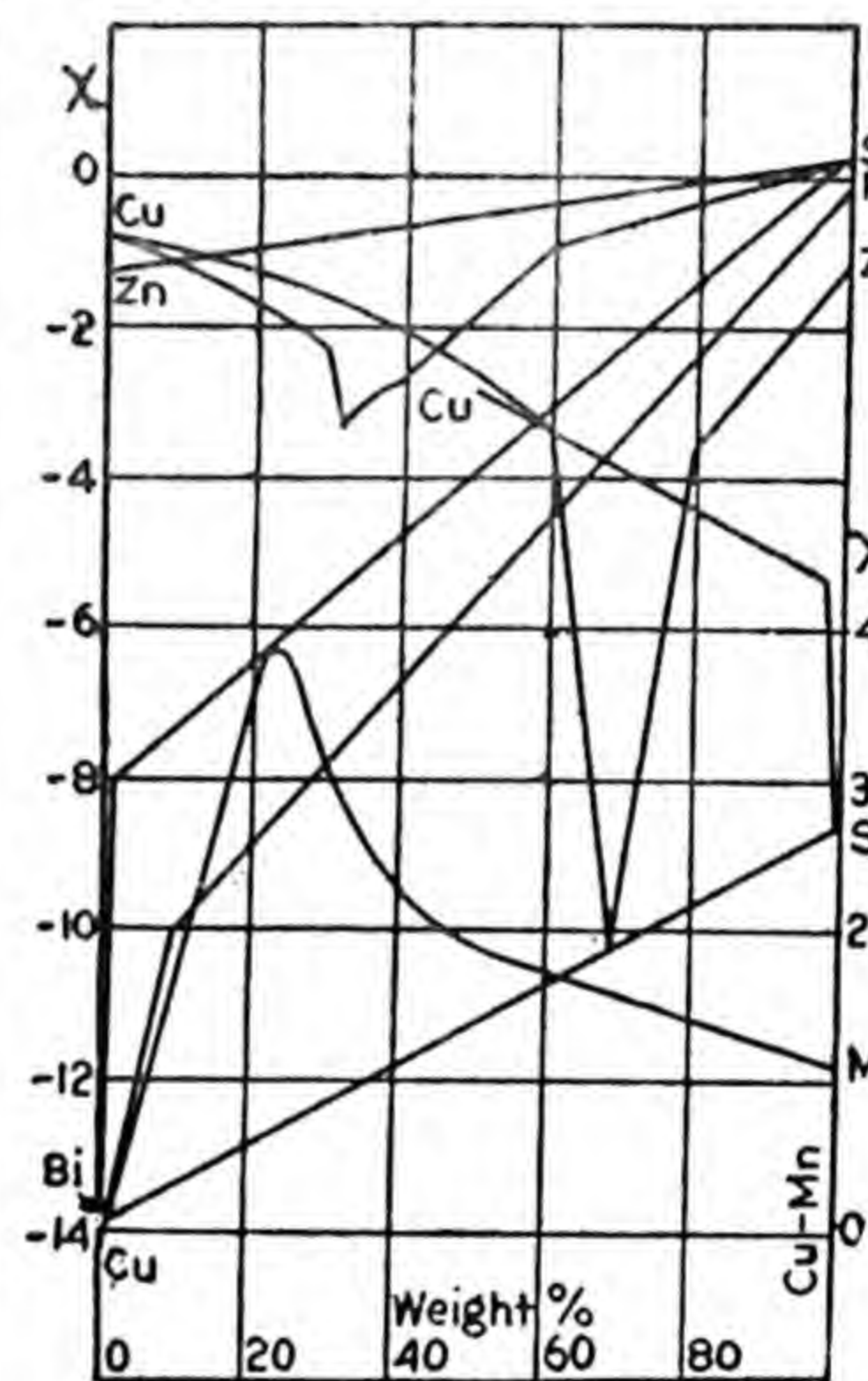


FIG. 3.

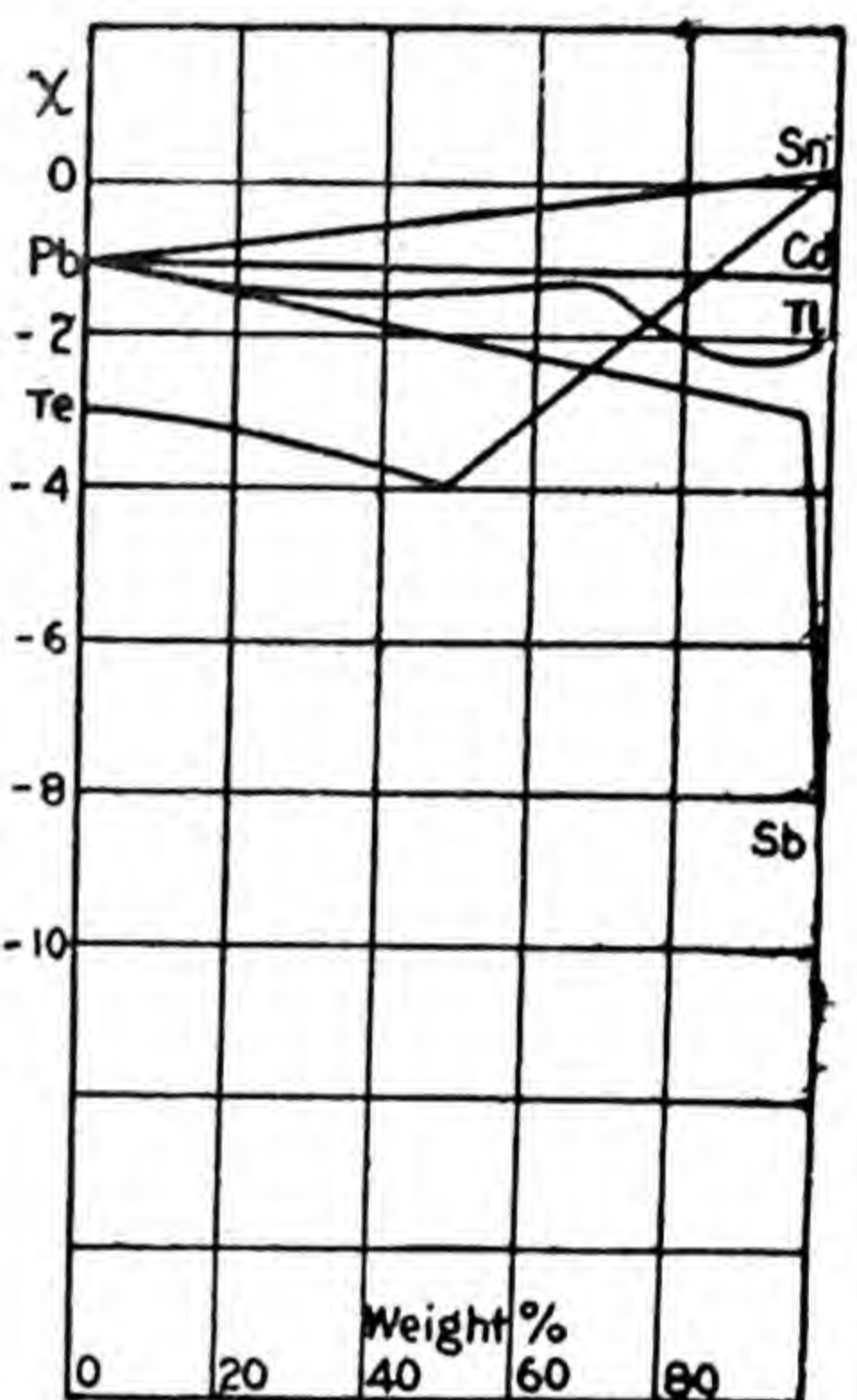


FIG. 4.

FIGS. 1, 2, 3, 4.—Susceptibility ( $\chi$ ) of alloys. Unit of  $\chi = 10^{-7}$  cgs. Abscissae indicate the weight % of the element named at the right margin.

## LITERATURE

(For a key to the periodicals see end of volume)

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## FERROMAGNETISM

PIERRE WEISS AND G. FOËX

## CONTENTS

## MATIÈRES

## INHALTSVERZEICHNIS

## INDICE

PAGE

Symbols.	Symboles.	Symbole.	Simboli.....	367
Units and conversion factors.	Unités et facteurs de conversion.	Einheiten und Umrechnungsfaktoren.	Unità e fattori di conversione.....	369
Numerical relations.	Relations numériques.	Numerische Beziehungen.	Relazioni numeriche.....	369
Definitions.	Définitions.	Definitionen.	Definizioni.....	369
Index Table: key number and composition of 167 specimens of Fe, Co, Ni, and their alloys, and alloys containing Mn and Cu.	Table index: nombre clé et composition de 167 échantillons de Fe, Co, Ni, et de leurs alliages, ainsi que d'alliages contenant Mn et Cu.	Index: Schlüsselzahl und Zusammensetzung von 167 Proben von Fe, Co, Ni, und deren Legierungen, ferner Legierungen mit Mn und Cu-Gehalt.	Indice: numero chiave e composizione di 167 campioni di Fe, Co, Ni e leghe relative, e campioni di leghe contenenti Mn e Cu.....	370
Illustrative data.	Données explicatives.	Erläuternde Daten.	Dati illustrativi.	
Normal, anhysteretic, and differential magnetization.	Magnétisation normale, sans hystérésis et différentielle.	Normale, anhysteresische und differentiale Magnetisation.	Magnetizzazione normale, senza isteresi, e differenziale.....	371
Effect of time.	Effet du temps.	Einfluss der Zeit.	Effetto del tempo.....	374
Magnetization in weak fields.	Magnétisation dans les champs faibles.	Magnetisierung in schwachen Feldern.	Magnetizzazione in campi deboli.....	374
Magnetization in intense fields.	Magnétisation dans les champs intenses.	Magnetisierung in starken Feldern.	Magnetizzazione in campi intensi.....	376
Effect of temperature.	Effet de la température.	Einfluss der Temperatur.	Effetto della temperatura.....	376
Electrolytic iron.	Fer électrolytique.	Elektrolytisches Eisen.	Ferro elettrolitico.....	378
Carbon irons and steels.	Aciers.	Kohlenstoff-Eisen und Stähle.	Acciai.	
Introduction.	Introduction.	Einleitung.	Introduzione.....	379
Hysteretic loss: effect of carbon and other admixtures.	Perte par hystérésis: effet du carbone et d'autres additions.	Hysteresis-Verluste: Einfluss der Kohle und anderer Beimengungen.	Perdita di isteresi: effetto del carbonio e di altre aggiunte.....	379
Coercive force: effect of carbon and of quenching temperature.	Force coercitive: effet du carbone et de la température de trempe.	Koerzitivkraft: Einfluss der Kohle und der Abschreckungs-Temperatur.	Forza coercitiva: effetto del carbonio e della temperatura di tempra	379
Cementite, pearlite, martensite.	Cémentite, perlite, martensite.	Zementit, Perlit, Martensit.	Cementite, perlite e martensite.....	380



Principal constants of annealed carbon irons.	Principales constantes des aciers recuits.	Hauptsächliche Konstanten des angelassenen Kohlenstoff-eisens.	Costanti principali degli acciai ricotti..... 380
Principal constants of quenched and drawn carbon irons.	Principales constantes des aciers trempés et étirés.	Hauptsächliche Konstanten des abgeschreckten und gezogenen Kohlenstoffeisens.	Costanti principali degli acciai temprati e rinvenuti..... 380
Normal and cyclic magnetization: various heat treatments.	Magnétisation normale et cyclique: traitements thermiques variés.	Normale und zyklische Magnetisierung: verschiedene Wärmebehandlung.	Magnetizzazione normale e ciclica: vari trattamenti termici... 381
Magnet steels.	Aciers à aimant.	Magnetstähle.	Acciaio per magneti.
Introductory.	Introduction.	Einleitendes.	Introduzione..... 385
Cyclic magnetization.	Magnétisation cyclique.	Zyklische Magnetisierung.	Magnetizzazione ciclica. 386
Coercive force and residual magnetization, and their variation with heat treatment.	Force coercitive et magnétisation résiduelle: leurs variations avec le traitement thermique.	Koerzitivkraft und Restmagnetisierung, deren Änderung mit der Wärmebehandlung.	Forza coercitiva e magnetizzazione residua e loro variazione con il trattamento termico.. 387
Effect of mechanical shock.	Effet du choc mécanique.	Einfluss mechanischer Erschütterung.	Effetto di urti meccanici..... 388
Effect of external magnetic field.	Effet du champ magnétique externe.	Einfluss eines äusseren Magnetfeldes.	Effetto di campi magnetici esterni..... 388
Temperature coefficient of magnetization.	Coëfficient de température de magnétisation.	Temperaturkoeffizient der Magnetisierung.	Coefficiente di temperatura della magnetizzazione..... 388
Alloys of iron.	Alliages de fer.	Eisen-Legierungen.	Leghe di ferro..... 390
Cobalt.	Cobalt.	Kobalt.	Cobalto..... 402
Nickel.	Nickel.	Nickel.	Nichel..... 403
Alloys of nickel.	Alliages de nickel.	Nickel-Legierungen.	Leghe di nichel..... 406
Manganese alloys and compounds.	Alliages et composés de manganèse.	Mangan-Legierungen und Verbindungen.	Leghe e composti di manganese..... 407
Transformation temperatures.	Températures de transformation.	Transformationstemperaturen.	Temperature di trasformazione..... 408
Crystals: iron, magnetite, pyrrhotite, and hematite.	Cristaux: fer, magnétite, pyrrhotite et hématite.	Kristalle: Eisen, Magnetit, Pyrrhotit, Hämatit.	Cristalli: ferro, magnetite, pirrotite ed ematite.... 410

Those materials to which most frequent reference will probably be made are listed in Table 1 in the order of their composition, and "key" numbers are there assigned them. In other places, they are, in general, identified by these key numbers only. Data for other alloys and compounds will be found in their appropriate places in the several tables. For a general exposition of the subject of ferromagnetism, see (77).

Les matières auxquelles il sera probablement fait appel le plus fréquemment sont disposées dans la Table 1 dans l'ordre de leur composition, et on a assigné à chacune d'elles un nombre "clé." Aux autres places, ces matières sont en général identifiées seulement par leurs nombres-clés. Les données relatives aux autres alliages et composés seront trouvées à leurs places appropriées dans les nombreuses tables. Pour une exposition générale du sujet du ferromagnétisme, voir (77).

Dasjenige Material, welches wahrscheinlich am häufigsten in Frage kommen wird, ist in der Tafel 1 in der Reihenfolge seiner Zusammensetzung angeordnet, und Schlüsselzahlen sind ihm angefügt. An anderer Stelle sind die Stoffe im allgemeinen nur durch die Schlüsselzahlen gekennzeichnet. Die Daten für andere Legierungen und Verbindungen sind an den zuständigen Stellen der verschiedenen Tafeln zu finden. Eine allgemeine Darlegung über den Ferromagnetismus, v. (77).

Le sostanze più interessanti sono elencate nella Tabella 1 secondo l'ordine della loro composizione e ad esse sono attribuiti numeri chiave con cui sono in genere designate. Dati per altre leghe e composti sono riportati nelle diverse tabelle. Per una esposizione generale sull'argomento del ferromagnetismo, v. (77).

SYMBOLS	SYMBOLS	SYMBOLS	SIMBOLI
Subscript Symboles	Symboles des Indices	Symbole für Indexzeichen	Simboli di Sottoscritti
a Annealed, if appended to designation of specimen or to $t$ .	a Recuit, si annexé à la désignation d'un échantillon ou à $t$ .	a Angelassen, wenn die Bezeichnung der Probe oder dem $t$ angefügt ist.	a Ricotto, se aggiunto alla designazione del campione o a $t$ .
a Alternating field, if appended to $W$ .	a Champ alternatif, si annexé à $W$ .	a Wechselstromfeld, wenn dem $W$ angefügt.	a Campo alternante, se aggiunto a $W$ .
c As cast, if appended to designation of specimen.	c Coulé, si annexé à la désignation d'un échantillon.	c Wie gegossen, wenn der Bezeichnung der Probe angefügt.	c Come ottenuto di getto, se aggiunto alla designazione del campione.
c Coercive, if appended to $H$ .	c Coercitif, si annexé à $H$ .	c Koerzitiv, wenn $H$ angefügt.	c Coercitivo, se aggiunto ad $H$ .



<i>d</i>	Drawn.	<i>d</i>	Étiré.	<i>d</i>	Gezogen.	<i>d</i>	Rinvenuto.
<i>l</i>	Value for large grains, <i>see</i> p. 379.	<i>l</i>	Valeur pour de gros grains, <i>voir</i> p. 379.	<i>l</i>	Werte für grobe Stücke, <i>siehe</i> S. 379.	<i>l</i>	Valore per grani grossi, <i>v. p.</i> 379.
max.	Maximum.	max.	Maximum.	max.	Maximum.	max.	Massimo.
<i>n</i>	Normal.	<i>n</i>	Normal.	<i>n</i>	Normal.	<i>n</i>	Normale.
<i>q</i>	Quenched.	<i>q</i>	Trempé.	<i>q</i>	Abgeschreckt.	<i>q</i>	Temprato.
<i>r</i>	Residual.	<i>r</i>	Résiduel.	<i>r</i>	Restlich.	<i>r</i>	Residuo.
red.	Reduced, corrected for presence of impurities.	red.	Réduit, corrigé à cause de la présence d'im- puretés.	red.	Reduziert, korrigiert wegen der Anwesen- heit von Verunreini- gungen.	red.	Ridotti, corretto per la presenza di impurezze.
<i>s</i>	Spontaneous.	<i>s</i>	Spontané.	<i>s</i>	Selbsttätig	<i>s</i>	Spontaneo.
<i>t</i>	Value at temperature <i>t</i> .	<i>t</i>	Valeur à la température, <i>t</i> .	<i>t</i>	Wert bei der Tempe- ratur, <i>t</i> .	<i>t</i>	Valore alla temperatura, <i>t</i> .
$\delta$	Differential or reversible.	$\delta$	Différentiel ou rever- sible.	$\delta$	Differentiell oder rever- sibel.	$\delta$	Differenziale o rever- sibile.
$\tau$	Turning or rotating.	$\tau$	Tournant ou animé d'un mouvement de rota- tion.	$\tau$	Drehend oder rotierend.	$\tau$	Girante o rotante.
0	Initial value, $H = 0$ .	0	Valeur initiale, $H = 0$ .	0	Anfangswert, $H = 0$ .	0	Valore iniziale, $H = 0$ .
$\infty$	Saturation value, $H$ very great.	$\infty$	Valeur de saturation, $H$ très grand.	$\infty$	Sättigungswert, $H$ sehr gross.	$\infty$	Valore di saturazione, $H$ molto grande.

Symbols for Quantities		Symboles pour Quantités		Symbole für Größen		Simboli per Quantità	
<i>a, a'</i>	Coefficients of magnetic hardness ( <i>see</i> defini- tion).	<i>a, a'</i>	Coëfficients de dureté magnétique ( <i>voir</i> défi- nition).	<i>a, a'</i>	Koeffizient der magneti- schen Härte ( <i>siehe</i> Definition).	<i>a, a'</i>	Coefficienti di durezza magnetica ( <i>vedi</i> defi- nizione).
<i>B</i>	Magnetic induction.	<i>B</i>	Induction magnétique.	<i>B</i>	Magnetische Induktion.	<i>B</i>	Induzione magnetica.
<i>B<sub>μ</sub></i>	Value of <i>B</i> correspond- ing to $\mu_m$ (max.).	<i>B<sub>μ</sub></i>	Valeur de <i>B</i> correspon- dant à $\mu_m$ (max.).	<i>B<sub>μ</sub></i>	Werte von <i>B</i> , die $\mu_m$ (max.) entsprechen.	<i>B<sub>μ</sub></i>	Valore di <i>B</i> corrispon- dente a $\mu_m$ (massimo).
<i>d</i>	Density; occasionally = diameter.	<i>d</i>	Densité; occasionnelle- ment = diamètre.	<i>d</i>	Dichte, zuweilen Durch- messer.	<i>d</i>	Densità, qualche volta = diametro.
<i>e</i>	Hysteresis exponent.	<i>e</i>	Exposant d'hystérésis.	<i>e</i>	Hysteresis-Exponent.	<i>e</i>	Esponente di isteresi.
<i>H</i>	Magnetic field intensity.	<i>H</i>	Intensité du champ mag- nétique.	<i>H</i>	Intensität des magneti- schen Feldes.	<i>H</i>	Intensità del campo magnetico.
<i>I</i>	Intensity of magneti- zation.	<i>I</i>	Intensité de magnéti- sation.	<i>I</i>	Intensität der Magneti- sierung.	<i>I</i>	Intensità della magnetis- zazione.
<i>l</i>	Length.	<i>l</i>	Longueur.	<i>l</i>	Länge.	<i>l</i>	Lunghezza.
Key	Key number as given in Table 1.	Key	Mêmes nombres-clés que ceux donnés dans la Table 1.	Key	Schlüsselzahl, wie in der Tabelle 1 vorhanden.	Key	Numero chiave ripor- tato nella Tabella 1.
<i>p</i>	Percentage by weight of constituent under con- sideration.	<i>p</i>	Pourcentage poids du constituant considéré.	<i>p</i>	Gewichtsprocente des betrachteten Konsti- tuenten.	<i>p</i>	Percentuale in peso del componente che si considera.
<i>s</i>	Side of section of square rod.	<i>s</i>	Côté d'une section d'une tige de section carrée.	<i>s</i>	Seitenlänge des Quer- schnittes eines vier- kantigen Stabes.	<i>s</i>	Lato di sezione di una sbarra quadrata.
<i>t</i>	Temperature, °C.	<i>t</i>	Température, °C.	<i>t</i>	Temperatur, °C.	<i>t</i>	Temperatura, °C.
<i>t<sub>R</sub></i>	Room temperature.	<i>t<sub>R</sub></i>	Température ambiante.	<i>t<sub>R</sub></i>	Zimmertemperatur	<i>t<sub>R</sub></i>	Temperatura ambiente.
<i>W</i>	Hysteresis loss per cm <sup>3</sup> per cycle.	<i>W</i>	Perte par hystérésis par cm <sup>3</sup> par cycle.	<i>W</i>	Hysteresisverlust pro cm <sup>3</sup> pro Cykl.	<i>W</i>	Perdita di isteresi per cm <sup>3</sup> e per ciclo.
$\alpha$	Temperature coefficient of electrical conduc- tivity; $(\rho_1 - \rho_0) =$ $\alpha\rho_0 t$ .	$\alpha$	Coëfficient de tempéra- ture de conductibilité électrique; $(\rho_1 - \rho_0) =$ $\alpha\rho_0 t$ .	$\alpha$	Temperaturkoeffizient der elektrischen Leit- fähigkeit; $(\rho_1 - \rho_0) =$ $\alpha\rho_0 t$ .	$\alpha$	Coefficiente di tempe- ratura della conduci- bilità elettrica; $(\rho_1 -$ $\rho_0) = \alpha\rho_0 t$ .
$\beta$	Temperature coefficient of <i>I</i> ; $I_1 - I_0 = \beta I_0 t$ .	$\beta$	Coëfficient de tempéra- ture de <i>I</i> ; $I_1 - I_0 =$ $\beta I_0 t$ .	$\beta$	Temperaturkoeffizient von <i>I</i> ; $I_1 - I_0 =$ $\beta I_0 t$ .	$\beta$	Coefficiente di tempe- ratura di <i>I</i> ; $I_1 - I_0 =$ $\beta I_0 t$ .
$\eta$	Hysteresis (Steinmetz) coefficient.	$\eta$	Coëfficient d'hystérésis (Steinmetz).	$\eta$	Hysteresiskoeffizient (Steinmetz).	$\eta$	Coefficiente di isteresi (Steinmetz).
$\theta$	Curie point, °C.	$\theta$	Point de Curie, °C	$\theta$	Curie-Punkt, °C.	$\theta$	Punto di Curie, °C.
$\kappa$	Susceptibility.	$\kappa$	Susceptibilité.	$\kappa$	Suszeptibilität.	$\kappa$	Suscettività.
$\lambda$	Wave-length in <i>vacuo</i> .	$\lambda$	Longueur d'onde dans le vide.	$\lambda$	Wellenlänge im Vakuum.	$\lambda$	Lunghezza d'onda nel vuoto.
$\mu$	Permeability.	$\mu$	Perméabilité.	$\mu$	Permeabilität.	$\mu$	Permeabilità.



$\rho$	Electrical volume resistivity.	$\rho$	Résistance électrique.	$\rho$	Elektrischer Widerstand.	$\rho$	Resistività elettrica.
$\sigma$	Specific magnetization; $\sigma = I/d$ .	$\sigma$	Magnétisation spécifique; $\sigma = I/d$ .	$\sigma$	Spezifische Magnetisierung; $\sigma = I/d$ .	$\sigma$	Magnetizzazione specifica; $\sigma = I/d$ .
$\sigma_{\infty}$	Saturation value of $\sigma$ at absolute zero.	$\sigma_{\infty}$	Valeur de saturation de $\sigma$ au zéro absolu.	$\sigma_{\infty}$	Sättigungswert von $\sigma$ beim absoluten Nullpunkt.	$\sigma_{\infty}$	Valore di saturazione di $\sigma$ allo zero assoluto.
$\sigma_{\infty}'$	Saturation value of $\sigma$ at temperature of observation.	$\sigma_{\infty}'$	Valeur de saturation de $\sigma$ à la température de l'observation.	$\sigma_{\infty}'$	Sättigungswert von $\sigma$ bei der Beobachtungstemperatur.	$\sigma_{\infty}'$	Valore di saturazione di $\sigma$ alla temperatura di osservazione.
$\tau_d$	Time specimen was kept at drawing temperature.	$\tau_d$	Temps durant lequel l'échantillon a été maintenu à la température d'étirage.	$\tau_d$	Zeitdauer während welcher die Probe bei der Temperatur gehalten wurde, bei welcher sie gezogen ist.	$\tau_d$	Durata di permanenza del campione alla temperatura di rinvenimento.
$\varphi$	Azimuth of $H$ .	$\varphi$	Azimuth de $H$ .	$\varphi$	$H$ -Azimut.	$\varphi$	Azimut di $H$ .
$\chi$	Specific susceptibility; $\chi = \kappa/d$ .	$\chi$	Susceptibilité spécifique; $\chi = \kappa/d$ .	$\chi$	Spezifische Suszeptibilität; $\chi = \kappa/d$ .	$\chi$	Suscettività specifica; $\chi = \kappa/d$ .

## Units and Conversion Factors

In the Ferromagnetic section of the Tables all data, excepting those for resistivity ( $\rho$ ), are expressed in cgsu units and centigrade temperatures, unless the contrary is explicitly stated; for  $\rho$  the unit is 1 microhm-cm.

$B$	1 cgsu = 1 maxwell $\text{cm}^{-2}$ = 1 line $\text{cm}^{-2}$ = 6.452 line $\text{in}^{-2}$ .
$d$	1 cgsu = 1 g $\text{cm}^{-3}$ = 0.03613 lb. $\text{in}^{-3}$ = 62.43 lb. $\text{ft}^{-3}$ .
$e$	A pure number.
$H$	1 cgsu = 1 gauss = 1 gilbert $\text{cm}^{-1}$ = 0.7957 ampere turn per cm = 2.021 ampere turn per in.
$I$	1 cgsu = 1 cgsu magnetic moment $\text{cm}^{-2}$ = $4\pi^*$ maxwell $\text{cm}^{-2}$ = $4\pi^*$ line $\text{cm}^{-2}$ = $6.452 \times 4\pi^*$ line $\text{in}^{-2}$ = 16.387 cgsu magnetic moment $\text{in}^{-2}$ .
$W$	1 cgsu = 1 erg $\text{cm}^{-3}$ per cycle = $10^{-7}$ watt $\text{cm}^{-3}$ per (cycle $\text{sec}^{-1}$ ) = $16.39 \times 10^{-7}$ watt $\text{in}^{-3}$ per cycle- $\text{sec}^{-1}$ = $d_M \times 10^{-7}$ watt $\text{g}^{-1}$ per cycle- $\text{sec}^{-1}$ = $16.39 d_E \times 10^{-7}$ watt $\text{lb}^{-1}$ per cycle- $\text{sec}^{-1}$ . ( $d_M, d_E$ are densities expressed in $\text{g cm}^{-3}$ , $\text{lb. in}^{-3}$ , respectively).
$\eta$	1 cgsu = 1 erg $\text{cm}^{-3}$ per cycle per (maxwell $\text{cm}^{-2}$ ) = 1 000 erg $\text{cm}^{-3}$ per cycle per (kiloline $\text{cm}^{-2}$ ) = $1 000 \times 10^{-7}$ watt $\text{cm}^{-3}$ per cycle- $\text{sec}^{-1}$ per (kiloline $\text{cm}^{-2}$ ) = $(155.0)^* \times 10^7$ watt $\text{cm}^{-3}$ per cycle- $\text{sec}^{-1}$ per (kiloline $\text{in}^{-2}$ ) = $16.387 \times (155.0)^* \times 10^7$ watt $\text{in}^{-3}$ per cycle- $\text{sec}^{-1}$ per (kiloline $\text{in}^{-2}$ ) = $16.387 \times (1 000)^* \times 10^{-7}$ watt $\text{in}^{-3}$ per cycle- $\text{sec}^{-1}$ per (kiloline $\text{cm}^{-2}$ ). (For $e = 1.6$ , $1 000^{1.6} = 63 096$ , $(155.0)^{1.6} = 3 195.4$ , $16.387 \times (155.0)^{1.6} = 52 364$ , $16.387 \times (1 000)^{1.6} = 1.0338 \times 10^6$ ).
$\kappa$	1 cgsu = $4\pi^*$ maxwell $\text{cm}^{-2}$ per gauss = $1.2566 \times 4\pi^*$ maxwell $\text{cm}^{-2}$ per ampere-turn- $\text{cm}^{-1}$ = $0.4947 \times 4\pi^*$ maxwell $\text{cm}^{-2}$ per ampere-turn- $\text{in}^{-1}$ = $6.452 \times 4\pi^*$ line $\text{in}^{-2}$ per gauss = $8.107 \times 4\pi^*$ line $\text{in}^{-2}$ per ampere-turn- $\text{cm}^{-1}$ = $3.192 \times 4\pi^*$ line $\text{in}^{-2}$ per ampere-turn- $\text{in}^{-1}$ .
$\mu$	1 cgsu = 1 maxwell $\text{cm}^{-2}$ per gauss = 1.2566 maxwell $\text{cm}^{-2}$ per ampere-turn- $\text{cm}^{-1}$ = 0.4947 maxwell $\text{cm}^{-2}$ per ampere-turn- $\text{in}^{-1}$ = 6.452 line $\text{in}^{-2}$ per gauss = 8.107 line $\text{in}^{-2}$ per ampere-turn- $\text{cm}^{-1}$ .
$\rho$	1 microhm-cm = 1 000 cgsu = $10^{-6}$ ohm-cm = 0.3937 microhm-in.
$\sigma$	1 cgsu = 1 cgsu magnetic moment $\text{g}^{-1}$ = $4\pi^*$ maxwell $\text{cm g}^{-1}$ = $4\pi^*$ line $\text{cm g}^{-1}$ = $178.6 \times 4\pi^*$ line $\text{in. lb}^{-1}$ = 453.6 cgsu magnetic moment $\text{lb}^{-1}$ .
$\chi$	1 cgsu = $4\pi^*$ maxwell $\text{cm g}^{-1}$ per gauss = $178.6 \times 4\pi^*$ line $\text{in. lb}^{-1}$ per gauss = 453.6 cgsu magnetic moment $\text{lb}^{-1}$ per gauss.

$$4\pi^* = 12.566; 0.4947 \times 4\pi^* = 6.217; 1.2566 \times 4\pi^* = 15.791; 3.192 \times 4\pi^* = 40.11; 6.452 \times 4\pi^* = 81.07; 8.107 \times 4\pi^* = 101.88; 178.6 \times 4\pi^* = 2244.4.$$

## Numerical Relations

$$\mu_n = B_n/H = 1 + 4\pi\kappa_n; \mu = B/H = 1 + 4\pi\kappa; B = H + 4\pi I; B_r = 4\pi I_r; I = \kappa H; I_n = \kappa_n H; \sigma = I/d = \chi H; \sigma_n = I_n/d; W = \eta B_{\max}^2. \text{ If } H \text{ is great, } 1/\kappa = a + bH; \sigma = \sigma_{\infty} (1 - a'H) \text{ if } \sigma > 0.99\sigma_{\infty}, a' = a\sigma_{\infty}.$$

## Definitions

**Anneal.**—When a specimen of material has been kept at a high temperature ( $t_a$ ) for such a length of time that it has come to equilibrium, and is then slowly cooled, it is said to have been annealed from  $t_a$ ;  $t_a$  = annealing temperature.

**Anhyseretic.**—Those data obtained when the specimen, while in a constant field ( $H$ ), is subjected to an alternating field which is progressively reduced from a value  $> H$  to 0. The same result can be obtained by subjecting the specimen to repeated mechanical shocks. To a first approximation, such data are single valued functions of  $H$ .

**Coercive Force.**—When the field, in which a specimen is placed, is reduced from a finite value ( $H_{\max}$ ) to 0,  $I$  is reduced to a certain finite value  $I_r$ , which is called the *residual magnetization* after the application of the force  $H_{\max}$ . The residual induction, or *retentivity*, is  $B_r = 4\pi I_r$ . In order to reduce  $B$  to 0, a reverse field of intensity  $H_c$  must be applied;  $H_c$  is the *coercive force*, or *coercive field*, corresponding to  $H_{\max}$ . When the value of  $H_{\max}$  (or of  $B_{\max}$ ) is not stated, it is understood to exceed that corresponding to saturation.

**Curie Point.**—Generally, the rising temperature at which the material ceases to be ferromagnetic, or the falling temperature at which it becomes ferromagnetic. These two temperatures do not coincide in all cases, and, unless the contrary is stated, it is to be understood that the observations were made with increasing temperature. More exactly, the Curie point is the temperature,  $\Theta$ , that occurs in the equation of Weiss,  $\chi(t - \Theta) = \text{constant}$ , which is satisfied by ferromagnetic materials if  $t$  is greater than, but not too nearly equal to  $\Theta$ . In this region  $\chi$  is independent of the field, and  $\chi^{-1}$  is linear in  $t$  (the linear law of Weiss). In a small transition region around  $\Theta$ , the graph of  $(\chi^{-1}, t)$  is curved; consequently this  $\Theta$  is, in general, a little higher than that at which ferromagnetism disappears. At the Curie point, the graph showing the variation of the specific heat with the temperature has a discontinuity and the reversible evolution of heat accompanying a change in  $H$  (the magnetocaloric phenomenon of Weiss) has a sharp maximum (77, 84, 85).

**Drawn.**—If an unannealed specimen is heated to a moderate temperature  $t_d$  for a time  $\tau_d$  and then cooled slowly it is said to have been *drawn* to the temperature  $t_d$  for the time  $\tau_d$ .



**Differential Susceptibility.**—If the intensity of the field is varied repeatedly over the range  $H$  to  $H-dH$ , the value of  $I$  ultimately varies between the fixed value  $I$  and  $I-dI$ , then  $dI/dH = \kappa_d$  is the *differential*, or *reversible*, susceptibility. The differential permeability is  $\mu_d = 1 + 4\pi\kappa_d$ . To a first approximation, these quantities are single valued functions of  $I$ .

**Hardness.**—If  $H$  is great,  $4\pi H/(B-H) = 1/\kappa = a + bH$ , where  $a$  and  $b$  are constants (<sup>37</sup>); and approximately  $\sigma = \sigma_\infty (1 - \frac{a'}{H})$ , where  $a' = aI_\infty$  (<sup>73</sup>). The quantities  $a$  and  $a'$  measure the magnetic hardness of the material. They vary with the impurities and with the heat treatment of the specimen.

**Hysteresis.**—When the field varies systematically and cyclically between  $+H_{\max}$  and  $-H_{\max}$ , the  $(B, H)$  curve, after a few cycles, is closed. This closed curve is called the *hysteresis loop*. During each cycle, there is dissipated within the specimen, and in addition to the dissipation by the Foucault currents, an amount of energy ( $W$ ) which is proportional to the volume of the specimen (if the field is uniform) and to the area of the loop. This is the *hysteretic loss*. It depends not only upon the specimen and the value of  $H_{\max}$ , but also upon the manner in which the cycle is traced—whether  $H$  varies by a series of finite steps, or is proportional to  $\sin \tau$ , or is constant in amount but varies in direction, etc. When  $H$  varies as  $\sin \tau$  ( $\tau = \text{time}$ ),  $W$  is called the *alternating hysteretic loss* and, when desirable, is denoted by  $W_a$ ; unless the contrary is stated,  $W$  will be understood to denote  $W_a$ . When the specimen is a body of revolution, and the field, constant in intensity, rotates uniformly about the axis of revolution—or the field is fixed and the body rotates— $W$  is called the *turning or rotating hysteretic loss*, denoted by  $W_r$ . As  $H_{\max}$  is increased,  $W_r$  passes through a maximum and tends to 0 in very intense fields. All hysteretic losses vary greatly with the heat treatment of the specimen. In general,  $W = \eta B_{\max}^e$ ;  $\eta = \text{hysteresis, or Steinmetz, coefficient}$ ;  $e = \text{hysteresis exponent}$ ; for most irons and steels,  $e = 1.6$ ; this value is to be assumed unless another is stated.

**Initial.**—The initial permeability ( $\mu_0$ ) is value of  $\mu$  when  $H = 0$ .  
**Normal.**—The permeability ( $\mu = B/H$ ) of a specimen depends upon its magnetic history, but the permeability ( $\mu_n = B_{\max}/H_{\max}$ ) at the tip of a repeatedly traced hysteresis loop is definite; it is called the *normal permeability* corresponding to  $H = H_{\max}$ . The corresponding susceptibility ( $\kappa_n$ ), induction ( $B_n$ ), and magnetization ( $I_n$ ) are likewise said to be *normal*. The locus of the positive tips of the hysteresis loops corresponding to various values of  $H_{\max}$  is called the *normal* ( $B, H$ ) curve, or the curve of first magnetization.

**Quenched.**—When a specimen while at a high temperature ( $t_q$ ) is quickly cooled by being plunged into a large volume of liquid (water, oil, mercury, etc.) it is said to have been quenched at temperature  $t_q$ .

**Reduced.**—Data which have been corrected for the effects produced by the impurities in the specimen are said to be "reduced," denoted by "red." (Constituents characteristic of the type of material under consideration are not impurities; e.g., in carbon irons, C is not an impurity, but in electrolytic iron, C is an impurity.)

**Residual.**—See Coercive force.

**Rotating Hysteresis.**—See Hysteresis.

**Saturation.**—The saturation values ( $\sigma_\infty, I_\infty$ ) of  $\sigma$  and  $I$  are their values at absolute zero and for  $H = \infty$ . Values ( $\sigma'_\infty, I'_\infty$ ) for  $H = \infty$ , but at temperature of observation (not absolute zero) are also called saturation values.

**Specific Magnetization.**—Magnetic moment per unit of mass;  $\sigma = I/d$ .

**Spontaneous.**—The magnetizations of the several structural elements composing a specimen are in general inclined to one another. Hence the observed, or apparent, magnetization of the specimen is less than the true magnetization of its elements. The latter may be determined by thermomagnetic measurements (<sup>75</sup>). Representing the latter as a function of  $H$ ,  $H$  great, and extrapolating to  $H = 0$ , a value called the *spontaneous magnetization* ( $I_s, \sigma_s$ ) of the material is obtained.

TABLE 1.—KEY NUMBER AND COMPOSITION OF EACH OF VARIOUS SPECIMENS OF IRON, COBALT, NICKEL, THEIR ALLOYS, AND ALLOYS CONTAINING MANGANESE AND COPPER

Those alloys which occur in only a single table and are of such a nature that there is no reason for comparing their compositions with those of others are not included in this list. When materials from distinctly different sources have the same composition, they are distinguished in the property tables by roman numerals appended to the key number. Amounts expressed in % by weight.

Key number	Material	% C	% Si	% Mn	% S	% P	Tables
<b>Carbon irons and pure Fe</b>							
1	Electrolytic Fe; fused in <i>vacuo</i> (3 mm Hg).....						4
1.1	Electrolytic Fe; fused in <i>vacuo</i> ; Heraeus; extremely pure.....						6
2	Electrolytic Fe; fused in <i>vacuo</i> ; total impurities = 0.02%.....						22
3	Electrolytic Fe; fused in H; Merck.....						6, 22
4	Electrolytic Fe; fused in N; Merck.....						4, 6, 22
5	Pure iron. Data obtained from commercial materials; correction applied for effect of impurities.....						4
6	Electrolytic Fe; fused in <i>vacuo</i> .....	0.0015			0.014		6
7	Electrolytic Fe; fused in <i>vacuo</i> .....	0.0017			0.014		6
8	Electrolytic Fe; fused in <i>vacuo</i> .....	0.0018			0.014		6
9	Electrolytic Fe.....	0.004	0.007		0.006	0.011	3 22
10	Electrolytic Fe; fused in <i>vacuo</i> .....	0.006	0.01				6
11	Iron, 0.006% Cu.....	0.009	0.005		0.009		22
12	Iron, 0.006% Cu.....	0.009	0.006		0.009		22
13	Electrolytic Fe; fused in H, 0.072% H.....	0.012	0.003	0	0.001	0.004	6
14	Electrolytic Fe + C.....	0.018	0.004	Tr.	0.011		9
15	Electrolytic Fe.....	0.024	0.004	0.008	0.001	0.008	6
16	Swedish charcoal iron.....	0.027	0.006	0.030	0.002	0.099	3, 4, 9, 11
17	Swedish charcoal iron.....						5
18	Mild steel; dynamo steel.....	0.044	0.004	0.400	0.027	0.044	3, 4, 9, 11
19	Swedish iron.....	0.046	0.006	0.12			5



TABLE 1.—(Continued)

Key number	Material	% C	% Si	% Mn	% S	% P	Tables
	Carbon irons and pure Fe.—(Continued)						
20	Taylor iron.....	<0.05					4
21	American ingot iron.....	<0.05					4
22	Norway iron.....	<0.05					4
23	Best refined iron.....	<0.05					4
24	Soft iron.....						2, 5, 11
25	Bessemer steel.....	0.05					4
26	Firminy.....	0.06					12, 14
27	Iron, 0.03% Cu.....	0.08	0.01	0.06	0.01	0.01	22
28	Mild steel; dynamo.....	0.085	0.028	0.380	0.024	0.029	4, 9, 11
29	Kohlsua iron.....	0.09	0.04	0.06	0.009	0.024	4
30	Bessemer steel.....	0.1					4
31	Electrolytic Fe + C.....	0.14	0.01	0.002	0.020		9
32	Bessemer steel.....	0.15					4
33	Firminy.....	0.20					12, 14
34	Hard steel.....	0.23	0.04	0.18	(?)	0.08	9, 11
35	Electrolytic Fe + C.....	0.23	0.006	0.004	0.020		9
36	Electrolytic Fe + C.....	0.32	0.007	Tr.	0.009		9, 10
37	Electrolytic Fe + C.....	0.39	0.004	Tr.	0.009		10
38	Mild steel, no As.....	0.44			0	0	5
39	Firminy.....	0.49					12, 14, 15
40	Electrolytic Fe + C.....	0.52	0.003	Tr.	0.011		9
41	Hard steel.....	0.69	0.16	0.13	0.08	0.02	9, 11
42	Firminy.....	0.84					12, 13, 14
43	Eutectoid steel,* 0.05% Cr.....	0.85	0.23	0.23	0.014	0.016	9, 11
44	Electrolytic Fe + C.....	0.88	0.018	0.006	0.011		9, 10
45	Electrolytic Fe + C.....	0.96	0.017	0.004	0.009		10
46	Unieux.....	0.96					12, 14
47	Hard steel.....	0.99	0.24	0.28	0.01	0.01	9, 11
48	High carbon steel.....	0.99	0.10	0.40	0.07	0.04	3
49	Drill rod.....	1.10					4
50	Firminy.....	1.21					12, 14
51	Electrolytic Fe + C.....	1.28	0.025	Tr.	0.008		9
52	Electrolytic Fe + C.....	1.32	0.006	Tr.	0.011		9
53	Unieux.....	1.40					14
54	Unieux.....	1.41					14
55	Electrolytic Fe + C.....	1.55	0.004	Tr.	0.003		9
56	Hard steel.....	1.57	0.23	0.37	0.01	0.01	9, 11
57	Electrolytic Fe + C.....	1.60	0.005	Tr.	0.005		9
58	Unieux.....	1.61					14
59	Hard steel.....	1.78	0.10	0.17	0.08	0.02	9, 11
	Silicon steels						
60	Silicon steel.....	0.25	1.03	0.09	0.04	0.02	17
61	Silicon steel.....	0.21	2.40	0.08	0.04	0.01	17
62	Stalloy.....		3				3
63	Silicon steel.....	0.06	3.71	0.31	0.01	0.01	17
64	Silicon steel†.....	0.07	4.09	0.10	0.01		17
65	Ferrosilicon.....		4.4				2
66	Dynamo sheets.....		4 to 5				3
67	Silicon steel.....	0.29	4.45	0.12	0.03	0.02	17
68	Series of alloys; Si = 0.001% to 4.92%; see.....						17
	Cast iron.....	3.109	3.270	0.560	0.061	1.050	4, 9, 11
	Manganese steels						
70	Manganese steel.....	0.46		0.7			12
71	Manganese steel.....	0.10	0.03	2.76			17
72	Manganese steel.....	0.09	0.04	4.20			17
73	Manganese steel.....	0.13	0.05	5.74			17
74	Manganese steel.....	0.20	0.09	7.81			17
75	Manganese steel.....	0.22	0.11	10.30			17
76	Manganese steel.....	0.20	0.13	12.34			17

\* The magnetic properties of commercial tool steel lie between those of the annealed and of the quenched eutectoid.  
† More recent than 60, 61, 63, 67.



TABLE 1.—(Continued)

Key number	Material	% Al	% C	% Si	% Mn	% S	% P	Tables
	Aluminium steels							
77	Aluminium steel.....	2.17	0.13	0.06	0.10			17
78	Aluminium steel.....	5.66	0.15	0.14	0.10			17
79	Aluminium steel.....	10.52	0.10	0.09	0.10			17
	Boron steels							17
		% W	% Cr	% Co				
	Cobalt steels							
79-a	Electrolytic Fe and pure Co (Merck), fused in H.....							17
80	Cobalt steel.....			10	1.37	4.7		23
81	Cobalt steel.....		5.4	10	1.22	3.9		13
82	Cobalt steel.....		5.1	20	1.11	3.5		13
83	Cobalt steel.....			22	1.16	4.4		13
84	"K. S." magnet steel; range.....	{ 5 9	1.5 3	30 40	0.4 0.8			12, 14, 16
85	Cobalt steel.....			33	1.15	4.4		13
86	Fe <sub>2</sub> Co.....			34.55				4, 17
87	Cobalt steel.....			35	0.83	4.8		13
88	Cobalt steel.....			35	1.12	4.7		13
89	Cobalt steel.....			35	1.24	4.0		13
90	Cobalt steel.....		4.8	36	1.11	3.5		13
	Chrome steels							17
	Copper iron alloys							17
				Mo				
	Molybdenum steel							
91	Châtillon and Commentry "A".....			3.5	0.51			13, 16
92	Châtillon and Commentry "B".....			3.4	1.25			13, 14, 16
93	Châtillon and Commentry "B".....			4.0	1.24			13, 15, 16
94	Châtillon and Commentry "C".....			5.9	1.72			13, 14, 16
		% Al	% Ni					
	Nickel iron alloys; nickel steels							
95	Electrolytic Fe, pure Ni.....							17
96	Electrolytic*.....	0.005	0.5	0.014	Tr.	Tr.	0.003	Tr.
97	Electrolytic* + Si.....	0.005	0.5	0.014	0.2	Tr.	0.003	Tr.
98	Electrolytic* + Si.....	0.005	1.0	0.014	0.2	Tr.	0.003	Tr.
99	Electrolytic*.....	0.005	1.96	0.014	0.001	Tr.	0.003	Tr.
100	Electrolytic* + Si.....	0.005	1.96	0.014	0.2	Tr.	0.003	Tr.
101	Nickel steel, "Ni 2".....		3	0.7				12
102	Electrolytic*.....	0.005	3.85	0.015	0.001	Tr.	0.003	Tr.
103	Electrolytic* + Si.....	0.005	3.85	0.015	0.2	Tr.	0.003	Tr.
104	Electrolytic*.....	0.005	5.68	0.015	0.002	Tr.	0.003	Tr.
105	Electrolytic* + Si.....	0.005	7.00	0.015	0.2	Tr.	0.003	Tr.
106	Electrolytic*.....	0.005	7.32	0.015	0.003	Tr.	0.003	Tr.
107	Electrolytic* + Si + Mn.....	0.005	8.0	0.016	0.2	0.1	0.003	Tr.
108	Electrolytic* + Si.....	0.005	9.52	0.016	0.2	Tr.	0.003	Tr.
109	Electrolytic*.....	0.004	9.61	0.016	0.004	Tr.	0.003	Tr.
110	Electrolytic* + 0.2% Ti.....	0.004	9.9	0.016	0.004	Tr.	0.003	Tr.
111	Electrolytic* + Mn + Si.....	0.004	10.0	0.016	0.2	0.1	0.003	Tr.
112	Electrolytic*.....	0.004	11.10	0.016	0.004	Tr.	0.003	Tr.
113	Electrolytic* + Si.....	0.004	15.0	0.017	0.2	Tr.	0.003	Tr.
114	Electrolytic* + 0.2% Ti.....	0.004	15.0	0.017	0.006	Tr.	0.003	Tr.
115	Electrolytic*.....	0.004	15.87	0.017	0.006	Tr.	0.003	Tr.
116	Electrolytic* + 0.2% Ti.....	0.004	20.0	0.017	0.008	Tr.	0.004	Tr.
117	Electrolytic*.....	0.004	21.03	0.017	0.008	Tr.	0.004	Tr.
118	Electrolytic* + Al.....	0.2	23.8	0.018	0.009	Tr.	0.004	Tr.
119	Electrolytic* + 0.2% Ti.....	0.004	25.0	0.018	0.010	Tr.	0.004	Tr.
120	Electrolytic* + Al.....	0.2	25.1	0.018	0.010	Tr.	0.004	Tr.
121	Electrolytic* + Al.....	0.2	29.8	0.019	0.012	Tr.	0.004	Tr.
122	Electrolytic* + Si.....	0.003	30.0	0.019	0.2	Tr.	0.004	Tr.
123	Electrolytic*.....	0.003	38.92	0.020	0.016	Tr.	0.004	Tr.

\* Both the Fe and the Ni are electrolytic; the Fe contains traces of Cu.



TABLE 1.—(Continued)

Key number	Material	% Al	% Ni	% C	% Si	% Mn	% S	% P	Tables
Nickel iron alloys; nickel steels.—(Continued)									
124	Electrolytic* + Mn.....	0.003	50	0.022	0.020	0.5	0.005	Tr.	17
125	Electrolytic*.....	0.002	54.08	0.023	0.022	Tr.	0.005	0.001	17
126	Electrolytic* + Mn.....	0.002	54.9	0.023	0.022	0.5	0.005	0.001	17
127	Electrolytic*.....	0.002	57.99	0.024	0.024	Tr.	0.005	0.001	17
128	Electrolytic*.....	0.002	66.96	0.025	0.027	Tr.	0.005	0.001	17
129	Electrolytic*.....	0.001	75.80	0.026	0.030	Tr.	0.005	0.001	17
130	Permalloy, 0.37% Co; 0.10% Cu.....		78.3	0.04	0.003	0.22	0.035	Tr.	17
131	Permalloy.....		78.5						3
132	Electrolytic* + Mn.....	Tr.	89.9	0.029	0.036	0.5	0.006	0.001	17
133	Electrolytic* + Mn.....	Tr.	93.3	0.029	0.037	0.5	0.006	0.001	17
134	Electrolytic* + Mn.....	0	99.2	0.030	0.040	0.5	0.006	0.001	17
		% Cr	% V						
Vanadium iron alloys									
135	Vanadium steel.....	0	3.5	0.60	Tr.	0.22			17
			% W						
Tungsten steels									
136	Assailly "V 2".....		2.7	0.76					12, 13
137	Assailly "V 3".....		2.7	1.10					13
138	Châtillon and Commentry "b".....		2.7	1.02					13
139	Assailly "V".....		2.9	0.55					13
140	Boehler† "special, extra hard".....		2.9	1.10					13, 14
141	Châtillon and Commentry "a".....		3.2	0.77					13
142	Châtillon and Commentry "c".....		3.5	1.53					13
143	Allevard.....		5.5	0.59					12, 13, 14, 15, 16
144	Boehler† "Boreas".....		7.7	1.96					13, 14, 15
Cobalt and nickel									
145	Cobalt; fused in <i>vacuo</i> ; 99% pure.....								4, 22
146	Cobalt.....								4, 18
146.1	Nickel; electrolytic, fused in <i>vacuo</i> ; from Heraeus; 99.9% pure.....								19
147	Nickel; fused in H; extremely pure, from Merck.....								19
148	Nickel; fused in N; extremely pure, from Merck.....								4
149	Nickel, Ni = 99.15%; Mn = 0.7%.....								19
150	Nickel, Ni = 98.08%, Co = 1.31%; Fe = 0.68%; insoluble = 0.11%.....								3
151	Nickel, contains 1.5% Co.....								19
152	Nickel; from Ni(CO) <sub>4</sub> .....								22
153	Nickel; purity not stated.....								19
Nickel alloys: Alloys with Fe, see Table 17 (Ni); others, see Table 20									
				% Pb	% Al	% Sn	% Mn	% Cu	
Manganese alloys containing Cu									
154	Heusler alloy.....				7.2		13.9	78.9	22
155	Heusler alloy (malleable).....				10.15		14.25	75.6	21
156	Heusler alloy.....				10.15		14.2	75.65	21
157	Heusler alloy.....				13.2		6.0	80.8	22
158	Heusler alloy.....				14.0		19.3	66.6	22
159	Heusler alloy (not malleable).....				15.0		23.5	61.5	21
160	Heusler alloy.....				16.3		26.5	57.2	22
161	Heusler alloy.....				25		11.6	63.4	22
162	Tin-manganese-copper alloy.....					14.1	25.1	60.2	21
163	Tin-manganese-copper alloy.....					16.1	24.5	58.7	21
164	Tin-manganese-copper alloy.....					18.0	23.9	57.6	21
165	Tin-manganese-copper alloy.....					29.8	20.4	49.2	21
166	Tin-manganese-copper alloy.....					38.0	18.1	43.4	21
167	Tin-manganese-copper alloy.....					48.1	15.0	36.4	21

\* Both the Fe and the Ni are electrolytic; the Fe contains traces of Cu.  
† Styria.



## Illustrative Data

TABLE 2.—ILLUSTRATIVE OF NORMAL, ANHYSTERETIC, AND DIFFERENTIAL MAGNETIZATION

See also Tables 5(19), 19(153I)  
24I, Soft iron; (cf. Table 11(24I))

$H$ (65)	Normal		Anhysteretic		Differential* (20)	
	$4\pi I_n$	$\mu_n$	$4\pi I$	$\mu$	$I$	$\mu_s$
0.04			5 570	150 000	0	91.2
0.14	170	1 200			165	89.7
0.22			8 680	40 000	308	85.0
0.23	690	3 020			491	77.5
0.54	5 160	9 560			593	74.6
0.62			11 280	18 100	799	62.1
0.73	6 940	9 500			1 010	45.2
3.67	13 730	3 740			1 100	37.4
5.51			14 800	2 690	1 230	22.6
7.79	14 930	1 920			1 370	13.8
20.7	15 970	770				
35.5			16 620	470		
37.4	16 660	446				
58.3			17 310	296		
71.2	17 560	248				
106.8	18 240	172	18 240	172		
164.5	19 100	177	19 100	117		

\* Does not refer to same material as the 4 preceding columns.

## 65 Ferrosilicon; 4.4% Si; anhysteretic (65)

$H$	$4\pi I$	$\mu$	$H$	$4\pi I$	$\mu$
0.01	850	85 000	2.49	9 870	3 960
0.02	1 400	70 000	8.41	12 750	1 520
0.05	1 970	40 000	38.6	14 670	380
0.15	3 290	21 000	60.0	15 350	257
0.58	5 200	9 000	179.9	17 640	99
1.39	7 820	5 600			

## EFFECT OF TIME

Irrespective of the action of Foucault currents, the magnetization of a material, in general, lags behind changes in  $H$ . For annealed soft iron, the lag is very marked; for other materials it is small. This effect is frequently ascribed to a magnetic viscosity; on account of it, the hysteresis cycle may vary markedly with the rate at which  $H$  is varied. At very high frequencies,  $\mu_n$  (max.) decreases rapidly as the frequency is increased, and at frequencies above  $3 \times 10^{10}$  per sec (wave-length  $\lambda$ ) in *vacuo* = 1 cm)  $\mu_n$  (max.) = 1, even for Fe (see Figs. 1 to 5).

TABLE 3.—MAGNETIZATION IN VERY WEAK FIELDS

When  $H$  is sufficiently small,  $\kappa = a + bH$  and  $W = \frac{1}{2}bH^2$  (57). The values of  $a$  and of  $b$  vary markedly with thermal treatment of the specimen. They vary in a very complicated fashion with the temperature, pass through an acute maximum near the Curie point, and become zero at that point. As the temperature changes progressively from  $-188^\circ\text{C}$  to Curie point, they satisfy the relation  $bc = a^2$ ; the values of  $c$  and of  $n$  depend upon the substance and its past thermal treatment. For composition, see Table 1.

TABLE 3.—(Continued)

9 Electrolytic iron ( $C = 0.004\%$ ) heated repeatedly to  $900^\circ\text{C}$ , alternating with cooling to  $700^\circ\text{C}$ , annealed from  $800^\circ\text{C}$ . At temperatures between 90 and  $150^\circ\text{C}$ , and at  $t > 330^\circ\text{C}$ , it ages very rapidly. At  $130^\circ\text{C}$  and  $H = 0.0957$ ,  $\kappa$  decreases to  $\frac{1}{2}$  its initial value in 10 hr and to  $\frac{1}{4}$  in 24 hr;  $n = 1.66$ ,  $c$  varies from 11 to 14 (58).

16 Swedish charcoal iron;  $C = 0.027\%$ , 16<sub>a</sub> = as cast, unannealed; 16<sub>s</sub> = annealed.

18 Dynamo steel;  $C = 0.044\%$ , 18<sub>a1</sub> = once annealed; 18<sub>a2</sub> = twice annealed.

48 High carbon steel;  $C = 0.99\%$ ; 48<sub>a</sub> = annealed; 48<sub>s</sub> = quenched.

62 Stalloy; Si = 3%.

66 Silicon steel, dynamo sheets; Si = 4 to 5%.

131I Permalloy; Ni = 78.5%.

150 Nickel ( $\text{Co} = 1.31\%$ ) in a condition, obtained by annealing, which was stable during observations between room temperature and Curie point;  $n = 4$ ,  $c = 1225$  (55). After annealing again,  $n = 4.09$ ,  $c = 2165$  ( $t$  increasing);  $n = 4.07$ ,  $c = 2145$  ( $t$  decreasing) (52), see Fig. 7;  $a = 7.188[(I_n - I)/I]^{1/2}$  (55).

Near Curie point ( $376^\circ\text{C}$ ) there is thermal irreversibility (52).

$\mu_n$ , permeability in weak fields: typical materials.

$H$	9	16 <sub>a</sub>	16 <sub>s</sub>	18 <sub>a1</sub>	18 <sub>a2</sub>	48 <sub>a</sub>	48 <sub>s</sub>	62	66	131I
0	750	214	470	490	320	72.8	43.2	320	528	10 500
0.01		222	513	522	351	72.8	43.2		554	13 800
0.03		242	600	586	433	72.8	43.3		611	36 300
0.05		266	680	650	540	72.9	43.4		668	
0.1		322	890	786	872	73.0	43.6		804	
0.15		374	1 070	912	1 390	73.1	43.8		930	
0.2		430	1 225	1 040	3 030	73.3	44.0		1 035	
0.3						73.5	44.2			
0.4						73.8	44.5			
Lit.	(58)	(26)	(26)	(26)	(26)	(26)	(26)	(46)	(26)	(28)

$\kappa$ , Susceptibility: typical materials ( $\kappa = a + bH$ )

Material	$4\pi a$	$4\pi b$	$H$ (limits)*	Lit.
9. Electrolytic iron (unannealed).....	102	8.5		(58)
9. Electrolytic iron.....	628	1358		(58)
9. Electrolytic iron.....	754			(58)
9 Electrolytic iron aged at $130^\circ\text{C}$ .....	201	176		(58)
Iron sheets.....	569	1106	0.07 to 0.75	(30)
Cast steel.....	235	168	0.07 to 0.9	(30)
Iron containing C.....	209	234	0.01 to 0.7	(30)
Iron wire, hard.....	74	22.0	0.1 to 1.1	(30)
Iron wire, not annealed.....	80	64		(57)
Cast iron.....	40	3.0	0.1 to 4.0	(30)
Tungsten steel, annealed.....	112	3.1	0.1 to 3.1	(30)
Tungsten steel, quenched....	28	0.4	0.1 to 3.5	(30)
Magnetite,† artificial.....	16.5	0.475	0.3 to 1.1	(58)

\* Limits of  $H$  within which  $\kappa = a + bH$ .

† Pure  $\text{Fe}_3\text{O}_4$  prepared by roasting  $\text{FeSO}_4$ ;  $n = 2.4$ ,  $c = 52.3$ ; see also p. 410.



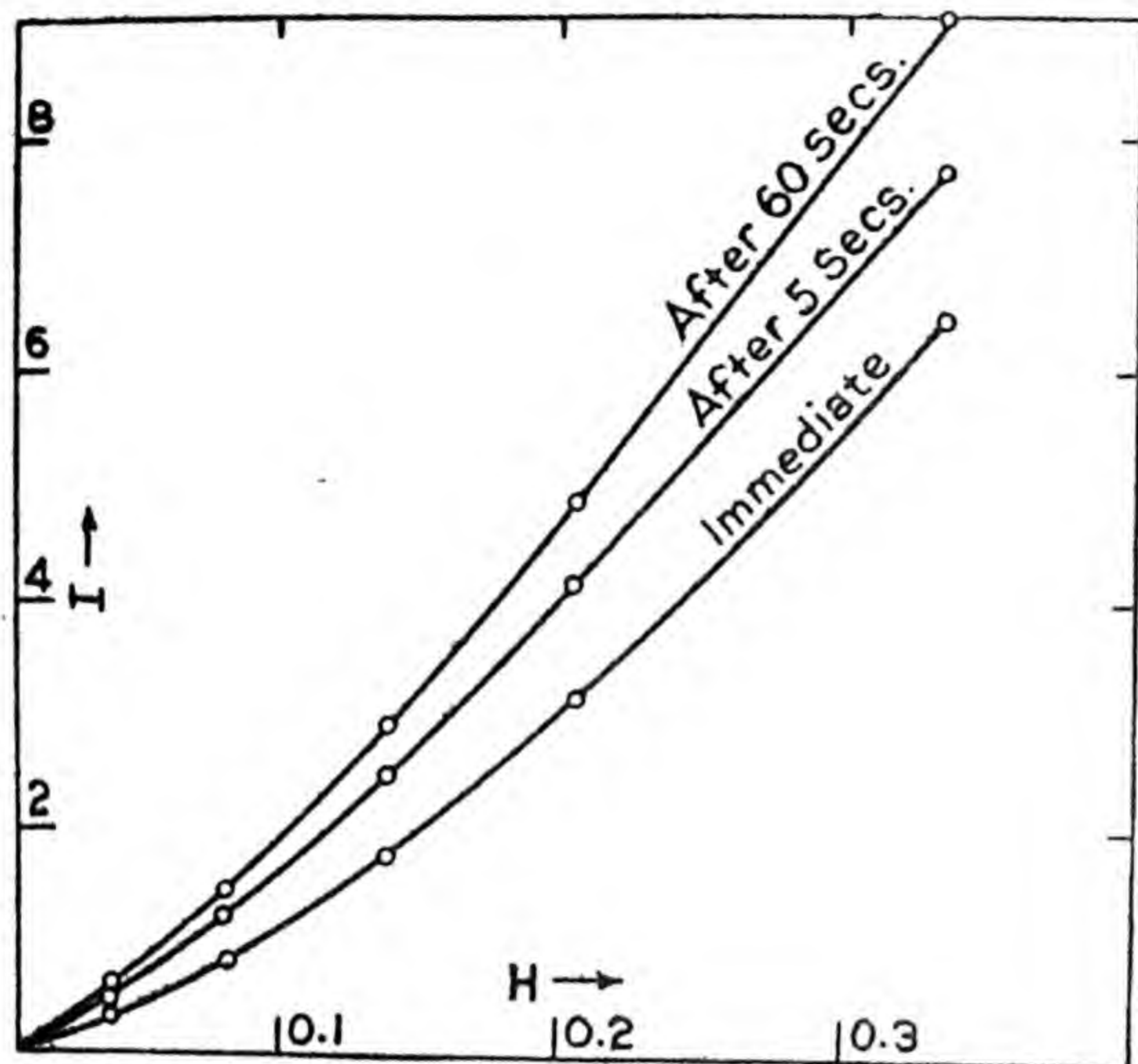


FIG. 1.—Time lag of magnetization ( $I$ ) in weak fields (<sup>16</sup>). Annealed, wrought iron wire.

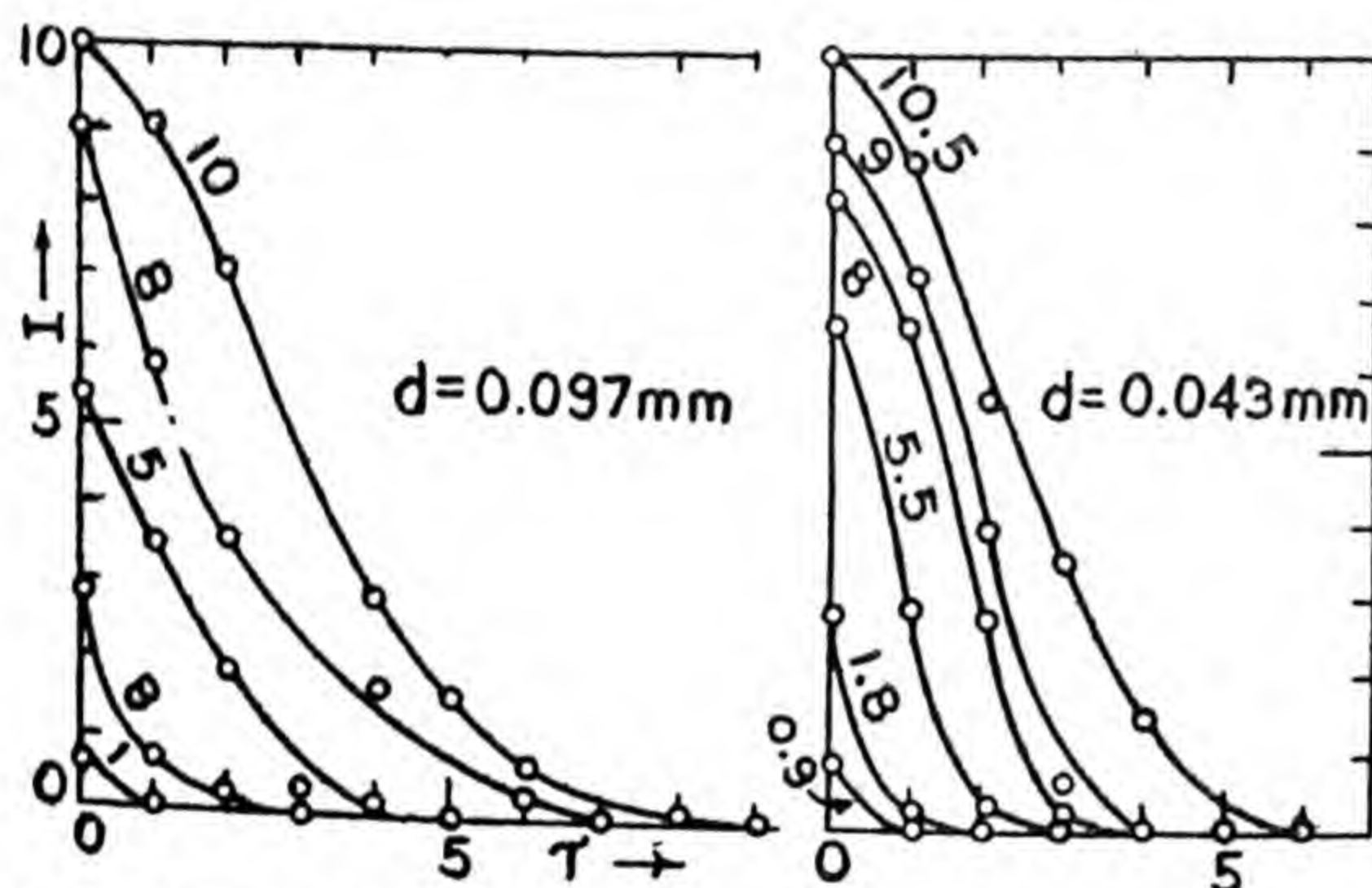


FIG. 3.—Time rate of decrease of magnetization (<sup>89</sup>). Hard steel wire, diameter =  $d$ ,  $H_c$  ca. 6. Values of  $I$  at various intervals after  $H$  has been reduced instantaneously to 0; initial value of  $H$  is marked on curve. Unit of  $\tau = 10^{-6}$  sec.

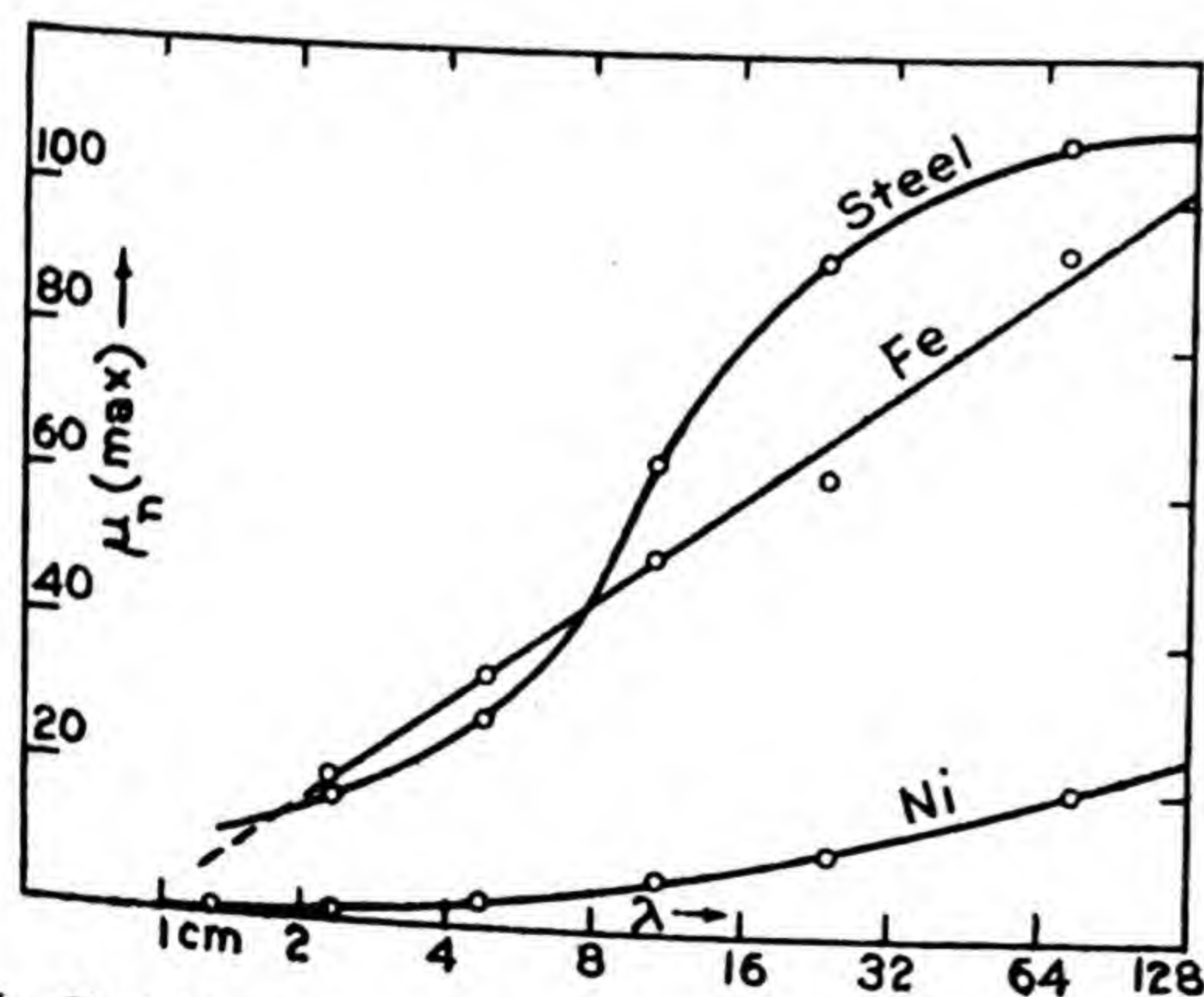


FIG. 5.—Variation of maximum permeability with frequency of  $H$  (<sup>2</sup>). (See also Fig. 4.)

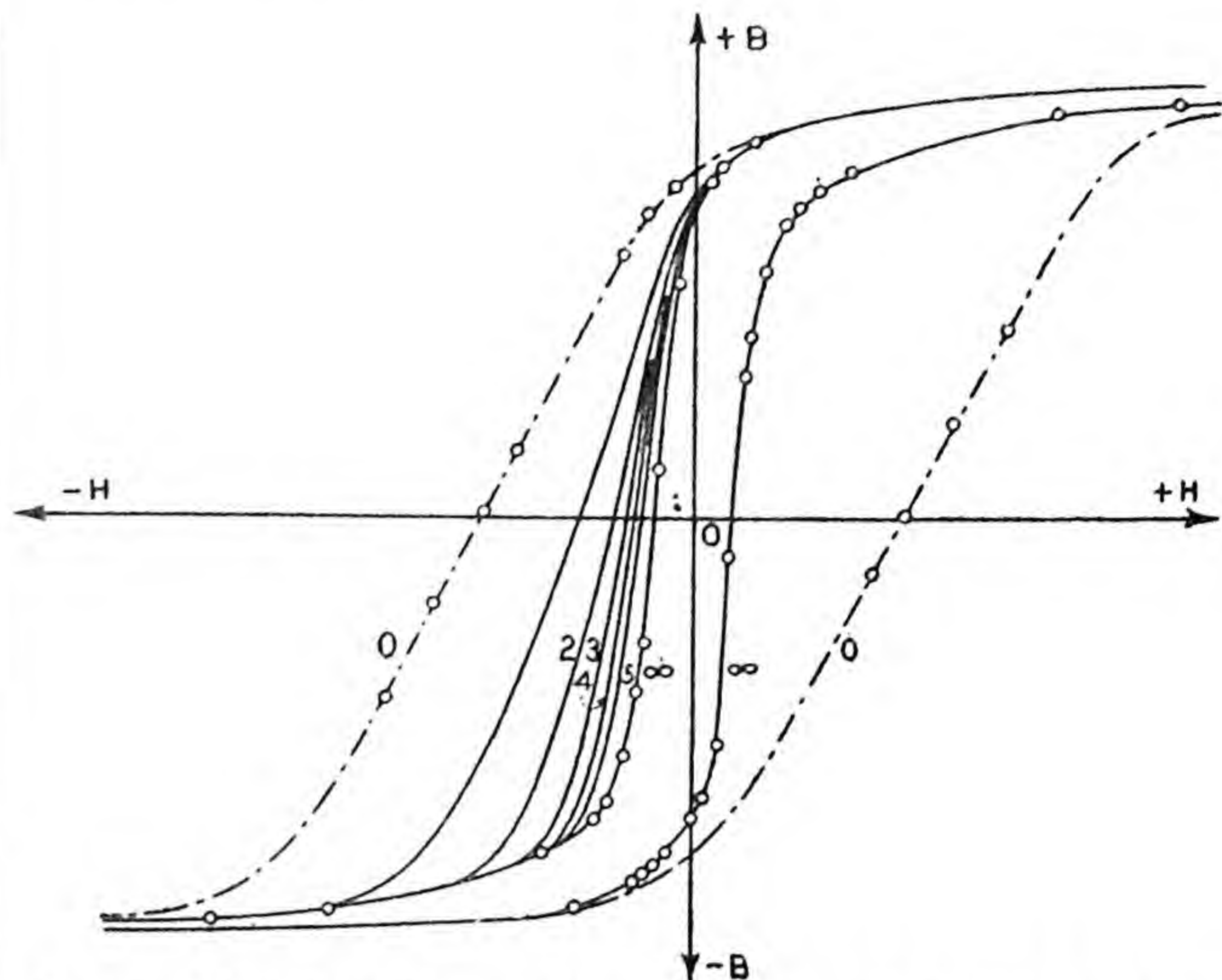


FIG. 2.—Variation of hysteresis cycle with rate of change of  $H$  (<sup>42</sup>). Annealed electrolytic iron. The curves are loci of isochronal values of  $B$ , obtained thus:  $H$  is instantaneously reduced from  $+H_{max}$  to a certain chosen fixed value, and  $B$  is measured at once and then after intervals of  $\frac{1}{3}$ ,  $\frac{2}{3}$ , ... sec. These ordinates and the chosen common abscissa define points on the curves 0, 1, 2, ...; the corresponding ascending curves are given for the intervals 0 and  $\infty$  only. For a very slow cycle,  $H_c = 0.39$ ; for a very rapid one,  $H_c = 2.18$ .

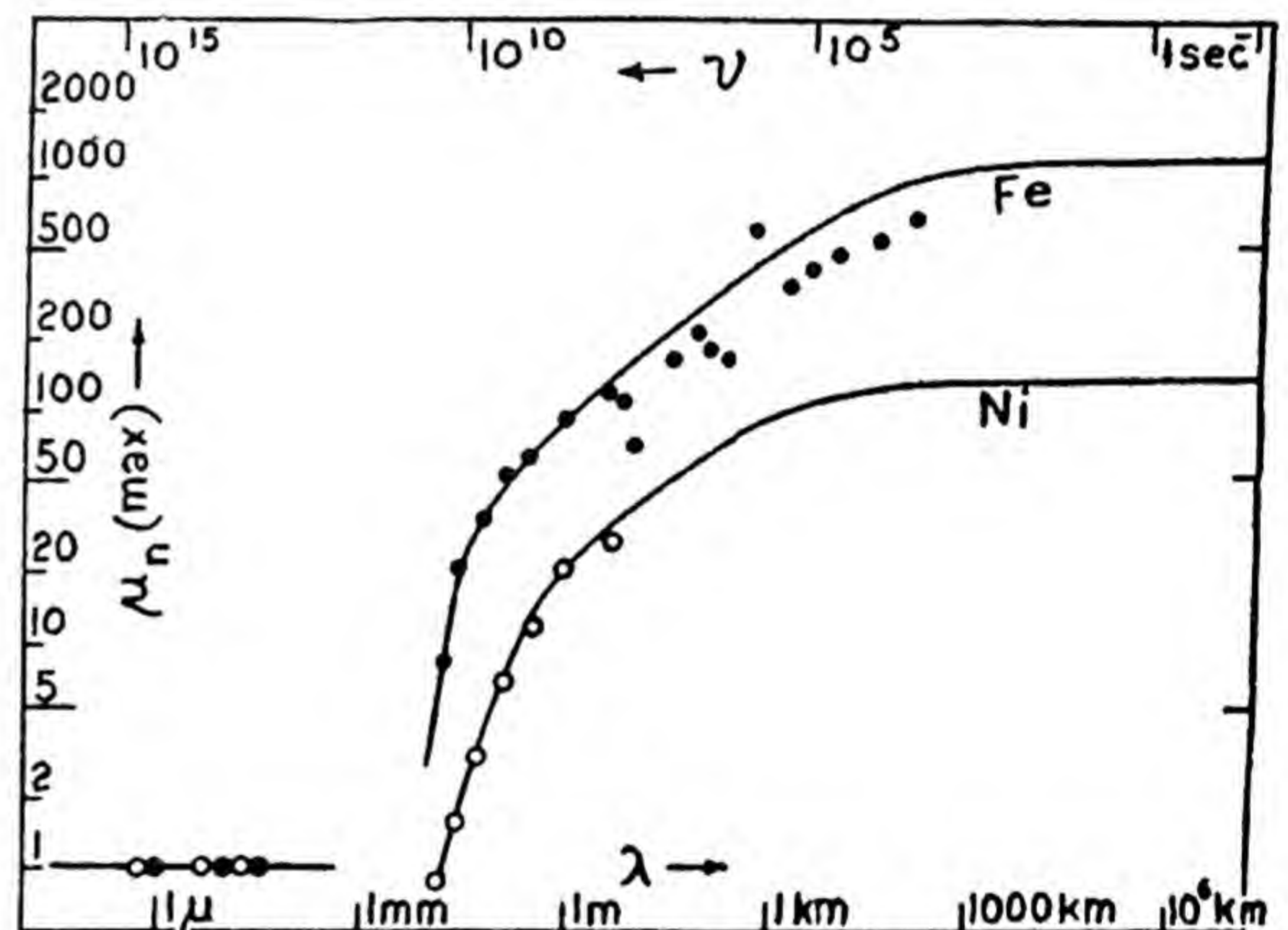


FIG. 4.—Variation of maximum permeability with frequency ( $\nu$ ) of  $H$ . Various authors, see (<sup>2</sup>).  $\lambda$  = wave-length in vacuo. See also Fig. 5.

TABLE 3.—(Continued)  
150;  $\kappa$ , Susceptibility: nickel (<sup>55</sup>)

$t$	$a$	$b$	$t$	$a$	$b$	$t$	$a$
18.5	3.68	0.154	244	5.68	0.861	+ 18	3.13
26.0	3.78	0.158	275	6.20	1.214	-183.1	0.954
47.0	3.90	0.187	293	6.60	1.511	-196.6	0.879
65.0	4.02	0.209	309	6.97	1.905	+ 18	3.06
80.0	4.11	0.236	322	7.44	2.402	-252.6	0.779
100.0	4.26	0.272	333	7.90	3.09	+ 18	3.06
124.5	4.44	0.323	344	8.73	4.54	(50)	
150.0	4.65	0.393	353	9.91	8.04		
179.0	4.90	0.502	357	11.65	14.55		
204.0	5.14	0.594	358	6.68	19.18		
220.0	5.37	0.708	376*	0	0		

\* Irreversibilities in this region (<sup>52</sup>).



TABLE 4.—MAGNETIZATION IN INTENSE FIELDS

The data here given are mainly illustrative; additional data of the same kind will be found in the tables giving data for specific materials. The relative accuracy of data of the same series and obtained by the same method is greater than the absolute accuracy.

For large values of  $H$ ,  $1/\kappa = a + bH$  (37) and approximately  $\sigma = \sigma_{\infty}(1 - a'/H)$  (73);  $a' = aI_{\infty}$ . Co is an exception; it is magnetically very hard, and in intense fields the law of variation of  $\sigma$  with  $H$  varies with the specimen; for a relatively soft Co,  $3600 < H < 6300$  gauss,  $\sigma = 162 \left[ 1 - \frac{1.11(10)^6}{H^2} \right]$  at  $17^{\circ}\text{C}$  (73). Both  $a$  and  $a'$  vary considerably with heat treatment and impurities. For composition, see Table 1.

1 Electrolytic iron, cast at pressure = 3 mm Hg.

4 Electrolytic iron, Merck, cast in N.

5 Pure iron (corrected for effects of impurities);  $d = 7.876$  g/cm<sup>3</sup>.

16 Swedish charcoal iron.

29 Kohlsch iron; C = 0.09%; 29' = corrected for effect of C, Si, Mn.

68 Cast iron; 68<sub>c</sub> = as cast; 68<sub>a</sub> = annealed.

86 Fe<sub>2</sub>Co; 86I<sub>1</sub> = cast under pressure of 1 mm Hg, forged; for 86I<sub>2</sub>, the pressure = 0.5 mm Hg. 86II, method of preparation is not stated.  $I_{\infty}(\text{Fe}_2\text{Co}) = 1.14I_{\infty}(\text{Fe})$ .

145 Cobalt, cast under pressure of 1 mm mercury.

146 Cobalt, relatively soft.

148 Nickel, Merck, cast in N.

Key	Material	$H$	$t$	$I_{\infty}$	$\sigma_{\infty}$	$a$	Lit.
1	Electrolytic iron.....		$t_R$	1798			(88)
4	Electrolytic iron.....	760	6500	17.3	216.1	7.9	(73)
5	Pure iron.....		$t_R$	1720			(22)
16 <sub>c</sub>	Swedish charcoal iron....		$t_R$	1685			(22)
18 <sub>c</sub>	Dynamo steel.....		$t_R$	1705			(22)
22 <sub>c</sub>	Dynamo steel.....		$t_R$	1691			(22)
29	Kohlsch iron.....	1500	6500	19	216.5	7.9	(73)
29'	Kohlsch iron.....		<6414	19	218.3*		(73)
68 <sub>c</sub>	Cast iron.....		$t_R$	1333			(23)
68 <sub>a</sub>	Cast iron.....		$t_R$	1307			(23)
86I <sub>1</sub>	Fe <sub>2</sub> CoI.....		$t_R$	2050			(88)
86I <sub>2</sub>	Fe <sub>2</sub> CoII.....		$t_R$	2056			(88)
86II	Fe <sub>2</sub> CoIII.....		$t_R$	1884			(23)
145	Cobalt, 99 %.....		$t_R$	1504			(88)
146	Cobalt, soft.....	3600	6300	17	162†	†	(73)
148	Nickel, pure.....	676	8380	18	54.5	9.7	(73)
	Magnetite†.....			19	90.7	39	(73)
	Magnetite, pure Fe <sub>3</sub> O <sub>4</sub> .....			19	93.3		(89)

\* Corrected for effect of C, Mn, Si.

† See text at head of table.

‡ Contains a little Fe<sub>2</sub>O<sub>3</sub>.

#### Other commercial irons and steels (52)

Key	Material	$H$	$I^*$	%C	Remarks†	21/1
						$H$ $I_{\infty}$
20I	Taylor.....	2490	1645	<0.05	slag >	40.5 1343
20II	Taylor.....	2685	1654	<0.05	slag >	68.8 1398
21I	American ingot.....	2760	1708	<0.05	ferrite	129.9 1476
21I'	American ingot.....	4395	1711	<0.05	ferrite	229.8 1570
21II	American ingot.....	2780	1725	<0.05	ferrite	271 1597
21II'	American ingot.....	4545	1735	<0.05	ferrite	399 1660
22I	Norway.....	2885	1685	<0.05	slag <	457 1684
22II	Norway.....	2770	1661		slag <	871 1715
22III	Norway.....	2770	1727		slag <	1126 1717
22IV	Norway.....	4360	1742		slag <	1569 1719
23I	Best refined.....	2740	1620	<0.05	slag >	2288 1724
23II	Best refined.....	2825	1589	<0.05	slag >	2747 1727
23III	Best refined.....	2690	1611	<0.05	slag >	4543 1735
25	Bessemer.....	2880	1671	0.05		
30I	Bessemer.....	2605	1663	0.1 ca.		
30II	Bessemer.....	2675	1687	0.1 ca.		
30III	Bessemer.....	2825	1666	0.1 ca.		
30IV	Bessemer.....	2370	1685	0.1 ca.		
32	Bessemer.....	2730	1727	0.15		
49	Drill rod.....	2790	1533	1.10		

\* Essentially =  $I'_{\infty}$ .

† After "slag," > denotes much; <, little.

TABLE 5.—EFFECT OF TEMPERATURE: SWEDISH IRON AND MILD STEEL

For Curie and other transformation points, see Table 22; for pure Fe, Co, Ni, see Tables 6, 18, 19; for Cu-Mn-Sn alloys, see Table 21; for magnet steels, see Table 16; for magnetite crystal, see Table 23; for composition, see Table 1.

Key	Material: description and notes
17I	Swedish iron; annealed 4 hr at 1000 to 1100°C; studied at 27°C, then plunged in liquid air and studied (34).
17II	Swedish iron; annealed in H. After giving it a known residual magnetization ( $I_r$ ) it was placed in field $H = 0$ (terrestrial and demagnetizing fields were compensated) and heated to successive temperatures at which the resulting values of $I$ ( $\equiv I_r$ ) were measured. Curves of ( $I_r, t$ ) are reversible and relatively homologous (Fig. 8); law of variation of $\sigma_r$ with $t$ is same as that of $\sigma_{\infty}$ with $t$ (Fig. 9) (49).
19	Swedish iron (C = 0.046%); annealed 20 min at 800°C ca.; thermal irreversibilities were not prominent (44).
24II	Soft iron; annealed at 800°C; relation between $H_c$ and $t$ is very definite and shows no thermal irreversibility (19).
38	Mild steel (C = 0.44%); wire; heated to 1200°C for a day, surrounded by porphyzied iron; during measurements it was sealed in Pt tube (14).

17I (34)				19* (44)			
27.5°C		-186°C		Normal		Anhystrere <sup>40</sup>	
$H$	$I_{\infty}$	$H$	$I_{\infty}$	$t_0$	$I_{\infty}$	$\mu_{\infty}$	$I$
1.77	81	2.23	77	15	10	1 380	435 6' 000
3.55	243	3.39	247	100			470 4' 800
4.10	582	4.55	453	200			523 2' 200
7.40	890	5.00	578	300	16	2 200	502 69 200
16.3	1 138	15.4	1 085	400			465 64 100
30.3	1 251	44.7	1 302	500	21.7	3 000	416 57 300
53.4	1 330	135.0	1 464	550			396 54 800
103.7	1 419	221.8	1 543	600	43.5	6 000	424 58 500
234.6	1 545	283.9	1 587	680			500 69 000
349	1 609	385	1 636	700	108	14 900	473 65 200
473	1 647	478	1 665	750	166	22 900	
554	1 621	543	1 681				

\*  $H = 0.091$  gauss.

17II (49)				17II (48)				24II (19)			
$t$	$\sigma_r/\sigma_r$	$t$	$W_r$	$W$	$W/W_r$	$t$	$H_c$	$t$	$H_c$	$t$	$H_c$
$t_R$	1.00	18	12 800	17 200	1.35	-185	2.44	467	1.49		
286	0.935	100	11 400	15 700	1.37	-79	2.36	493	1.44		
405	0.854	200	9 980	13 800	1.38	+21	2.28	553	1.22		
517	0.743	300	8 240	11 600	1.41	220	2.00	607	1.09		
605	0.655	400	6 020	8 560	1.42	303	1.84	643	1.01		
653	0.596	500	3 580	4 900	1.36	360	1.70	656	0.84		
763	0.000	600	2 540	2 760	1.08	385	1.53	670	0.71		
		700	873	896	1.02	419	1.48	721	0.74		
		760	0	0							

$H_{\max} = 950$  gauss.

38 $\sigma$ , Specific magnetisation (14); see Fig. 10					
$H$	20.0°C	275.0°C	477.0°C	601.0°C	688.0°C
10		117(?)	117(?)	114(?)	89(?)
15	123(?)	126(?)	129(?)	129	100
25	136.0	138	140.5	137.0	108.6
50	153.7	151.8	155.0	147.8	114.7
75	164.3	162.0	166.2	152.0	117.9
100	171.8	171.1	173.0	154.9	119.9
150	183.7	184.3	180.3	158.8	121.8
300	201.3	200.3	186.8	162.9	124.7

Continued on p. 378



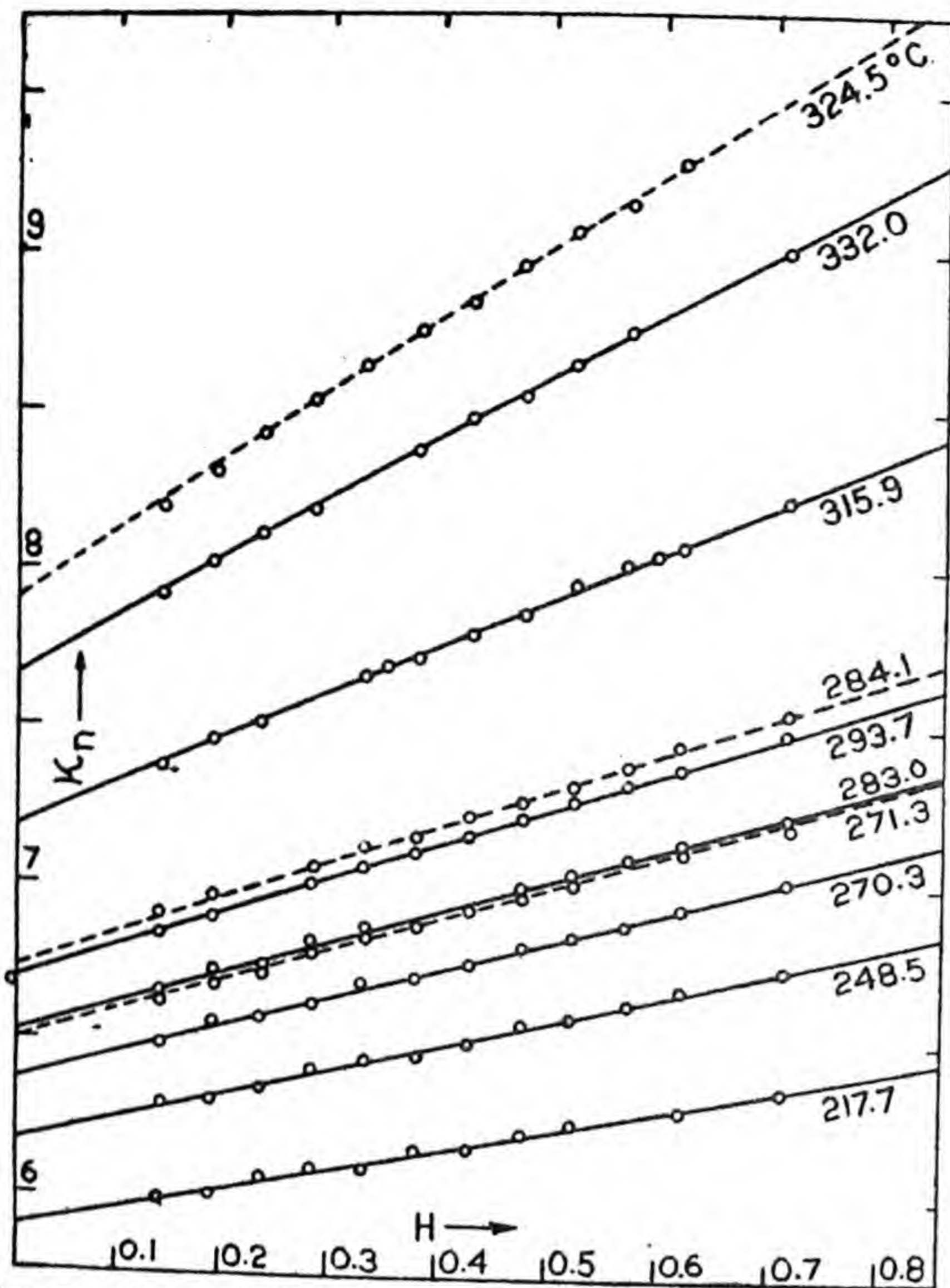
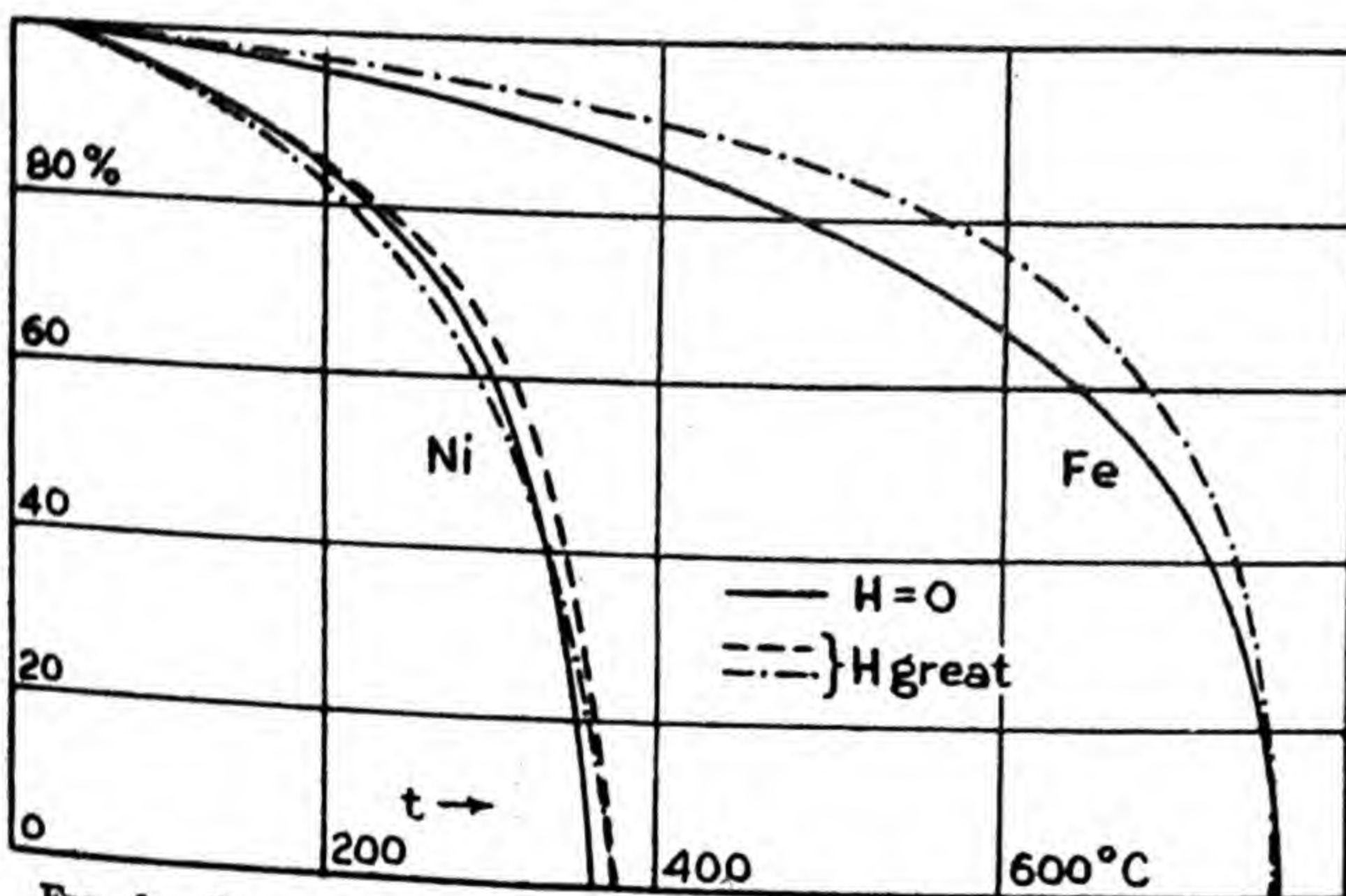
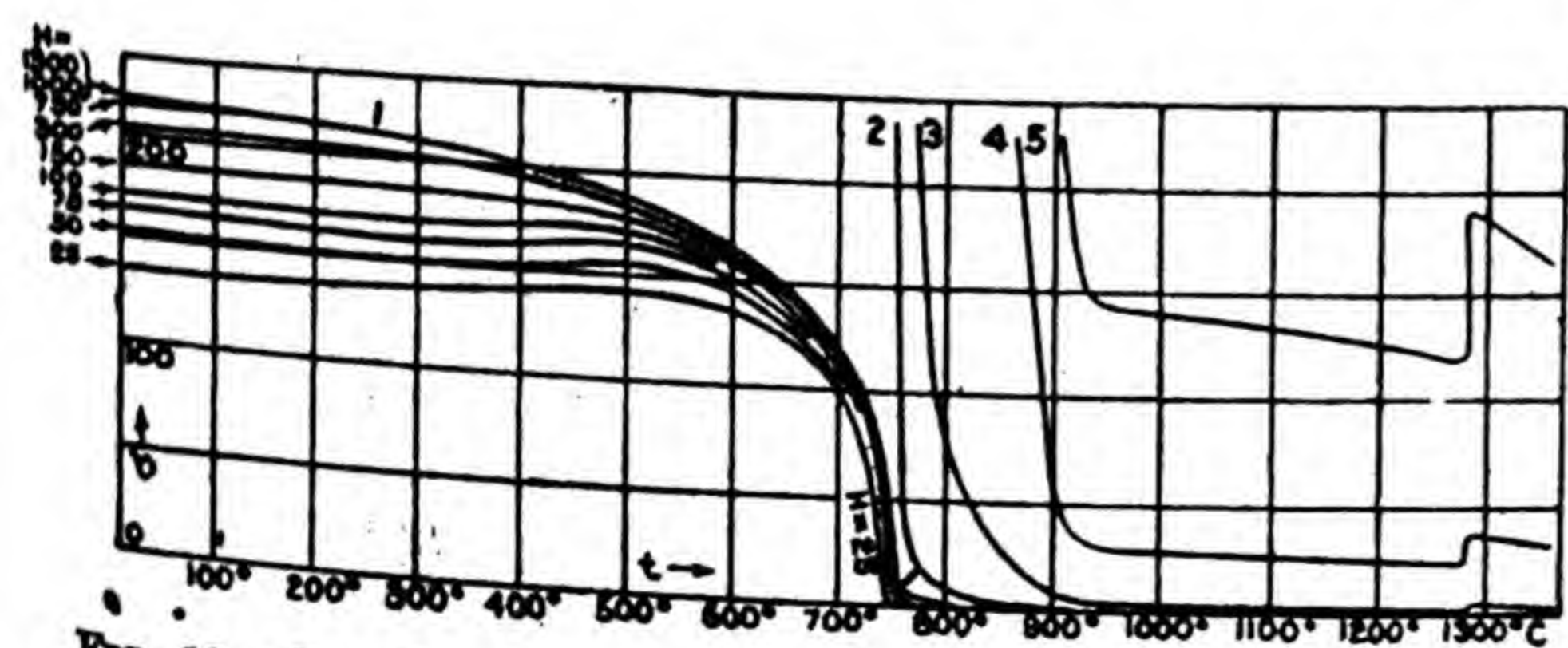
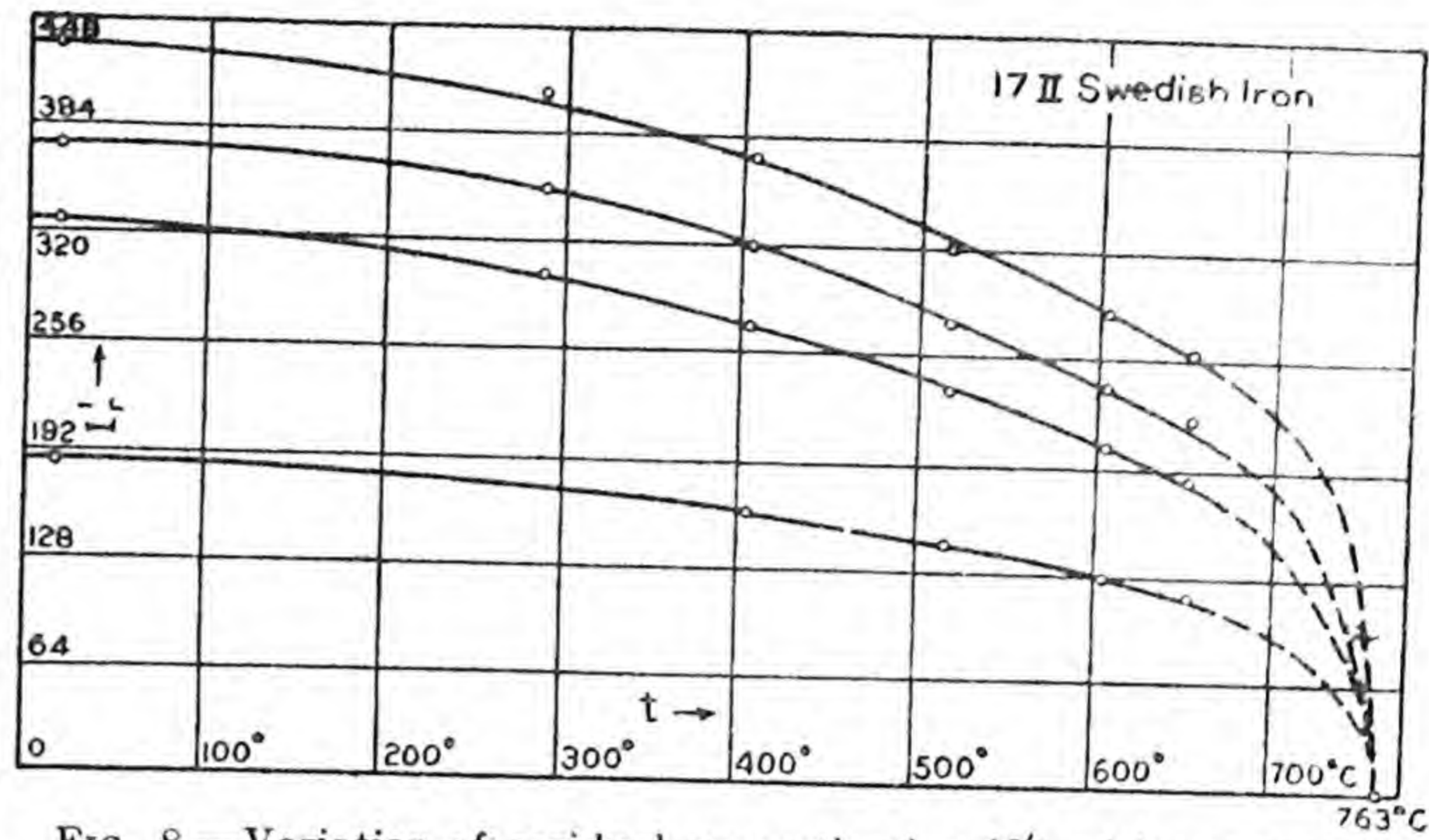
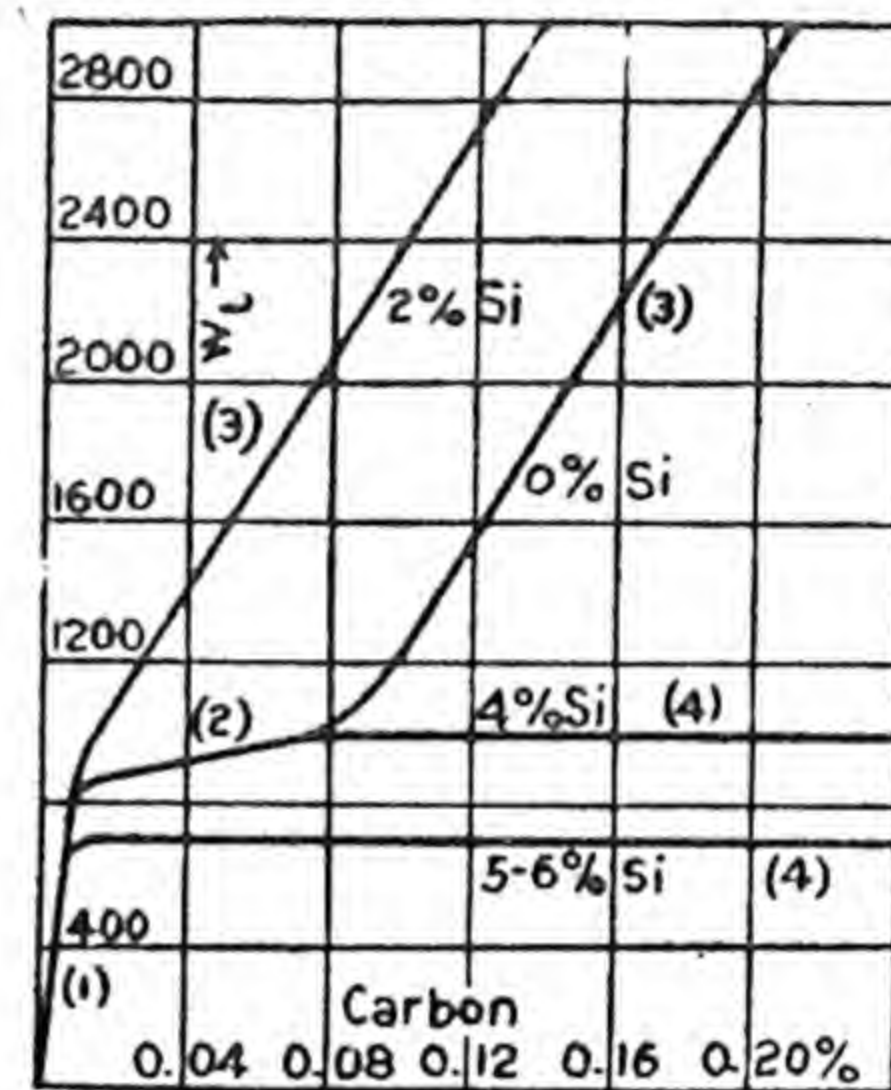
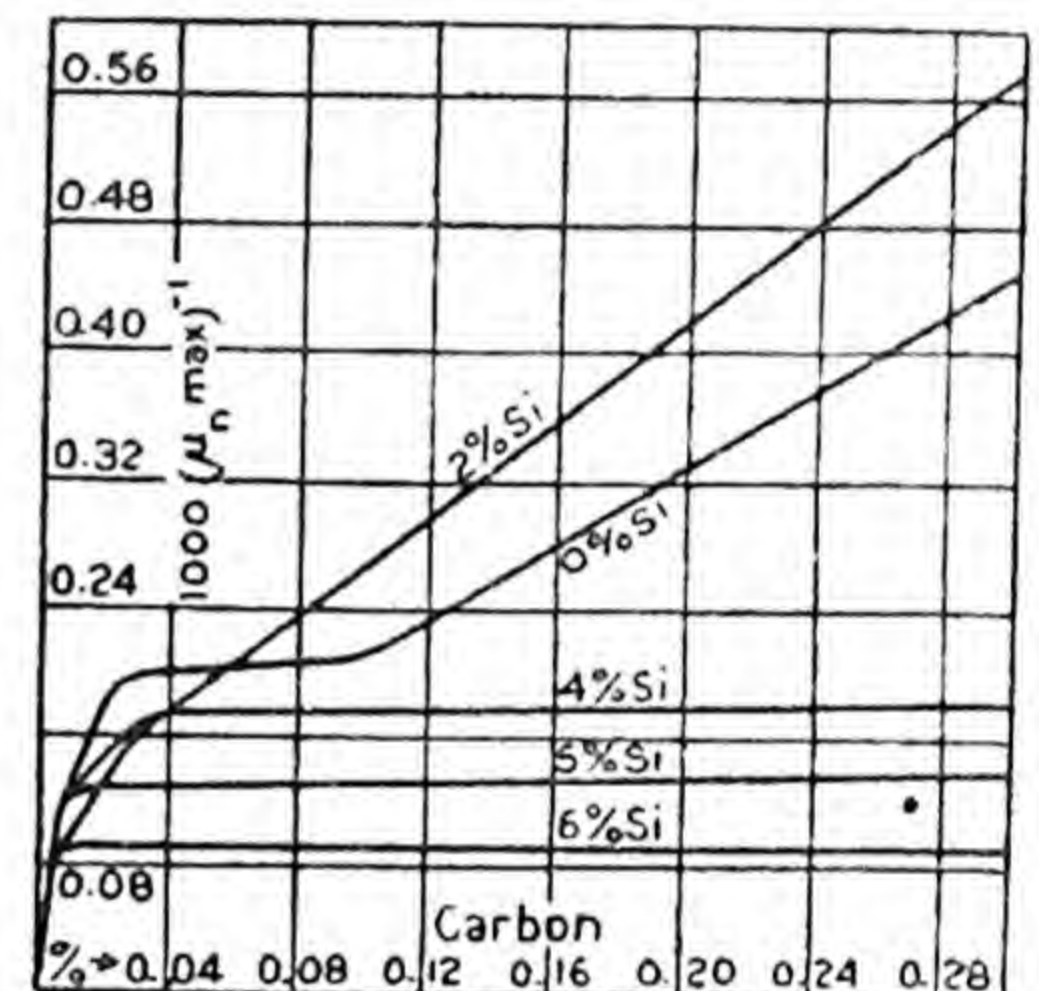

 FIG. 7.—Susceptibility ( $\kappa_n$ ) of nickel (160) in weak fields (82)

 FIG. 9.—Temperature variation of residual magnetisation ( $\sigma_r$ ) and of magnetization at saturation ( $\sigma_{\infty,t}$ ). Various authors, v. (49). Ordinates are  $\sigma_r/\sigma_{r0}$ , if  $H = 0$ ;  $\sigma_{\infty,t}/\sigma_{\infty,0}$  if  $H$  is great. At room temperature and  $H = 0$ , residual magnetisation is  $\sigma_r$ ; keeping  $H = 0$ , the specimen is heated to temperature  $t$  and the magnetization becomes  $\sigma_r$ .

 FIG. 10.—Specific magnetisation ( $\sigma$ ) of mild steel 38 (14). Curves 2, 3, 4, 5 represent portions of curve 1 with ordinates magnified 10, 100, 1000, and 5000 times, respectively; v. also Table 5.

 FIG. 8.—Variation of residual magnetization ( $I_r$ ) with temperature (49). The specimen is magnetized to a certain value of  $I_r$  when at room temperature and in zero field. It is then heated in zero field to several successively higher temperatures and at each the magnetization ( $I_r$ ) remaining is measured. Thus a curve for each initial value of  $I_r$  is obtained; cf. Table 5.

 FIG. 11.—Effect of C and of Si upon hysteric loss (94). Effect of other impurities has been eliminated.  $B_{max} = 10\,000$ . In region (1), C is in solution,  $dW/dC = 100\,000$ ; in (2), C is in form of  $Fe_3C$ ,  $dW/dC = 2\,500$ ; in (3) C is in form of pearlite,  $dW/dC = 16\,500$ ; in (4), C exists as graphite,  $dW/dC = 0$ ; unit of C = 1 %.


FIG. 13.—Effect of C and of Si upon permeability (94). Not corrected for size of grain; cf. Figs. 14, 15.

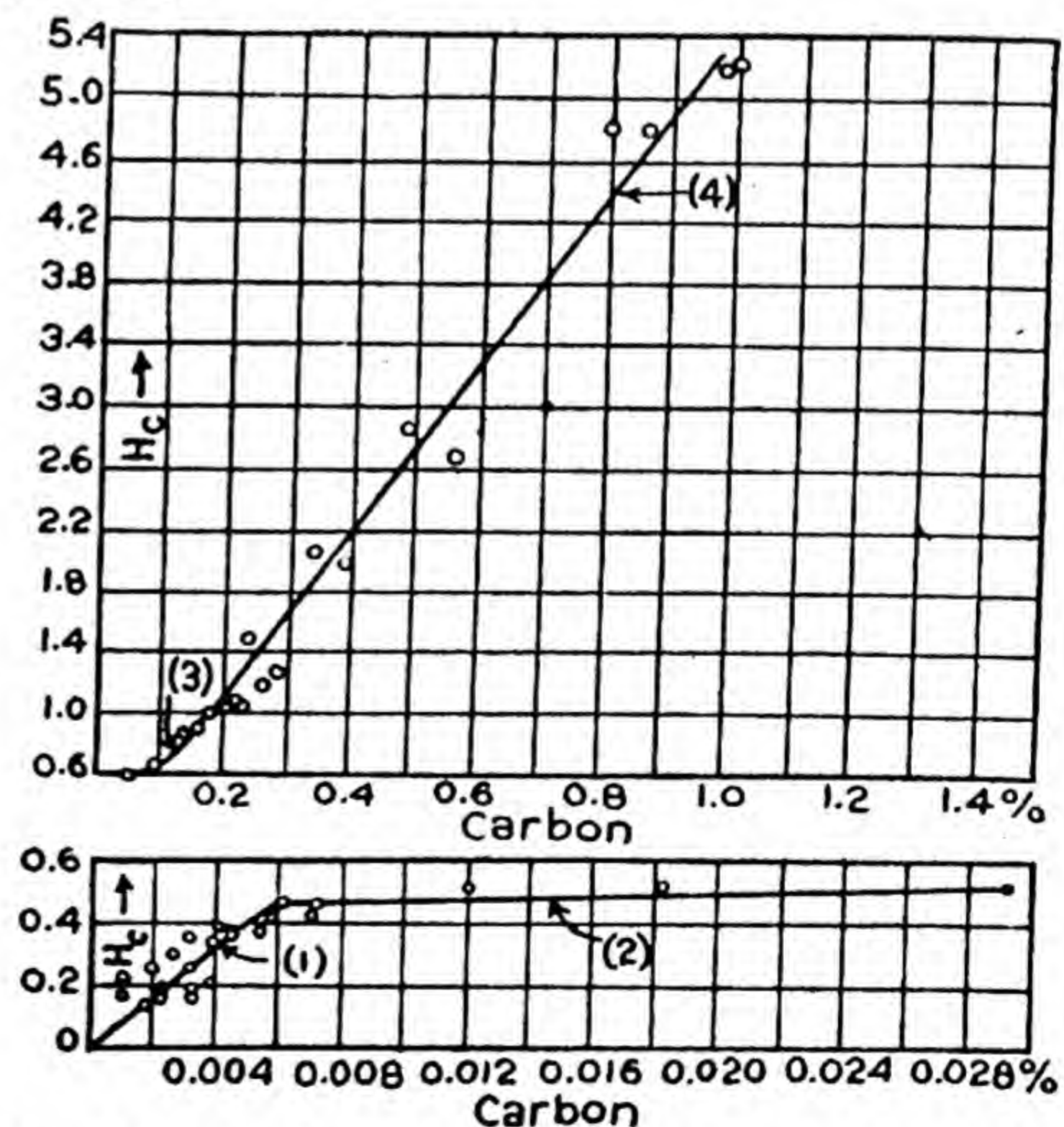

 FIG. 12.—Effect of C upon coercive force (94). Not corrected for size of grain. In region (1), C is in solution,  $H_c = 80C$ ; in (2)  $dH_c/dC = 2.5$ ; in (3), cementite,  $dH_c/dC = 0.8$ ; in (4), pearlite,  $dH_c/dC = 5.4$ ; unit of C = 1 %; v. also Table 8.



TABLE 5.—(Continued from p. 376)

38		$\sigma$ , Specific magnetization ( <sup>14</sup> ); see Fig. 10				
$H$	$t$	20.0°C	275.0°C	477.0°C	601.0°C	688.0°C
750		215.7	207.1	188.9	164.0	126.8
1000		216.2	207.5	189.5	164.0	127.1
1300		216.3	207.5	189.6	164.0	127.1

38		$\sigma$ , Specific magnetization ( <sup>14</sup> ); see Fig. 10				
$H$	$t$	720.0°C	740.4°C	744.6°C	748.2°C	752.2°C
15		82				
25		84.5	46.0	27.0	6.5	
50		88.4	50.5	29.5	8.7	
75		91.0	53.0	31.0	10.0	
100		92.9	55.2	32.5	11.5	
150		94.4	57.1	34.6	14.0	3.5
300		97.8	58.5	39.2	19.4	5.3
750		100.1	61.3	45.4	29.2	12.2
1000		100.4	62.3	47.6	31.1	15.0
1300		100.7	64.0	50.1	37.3	18.2

38		$\sigma$ , Specific magnetization ( <sup>14</sup> ); see Fig. 10				
$H$	$t$	756.4°C	760.5°C	764.4°C	767.9°C	780.4°C
100		0.74	0.45	0.34	0.27	0.145
150		1.11	0.67	0.51	0.40	0.20
300		2.22	1.35	1.02	0.81	0.43
750		5.55	3.38	2.55	2.03	1.09
1000		7.4	4.5	3.4	2.7	1.45
1300		9.62	5.85	4.42	3.51	1.88

## Electrolytic Iron

TABLE 6.—MAGNETIC PROPERTIES

For properties in very weak and in very intense fields, see Tables 3 and 4; for impurities, see Table 1

Key	Remarks
1.1	Heraeus. Fused in vacuum. Very pure; the mere traces of impurities contained in it are too small to be measured by the usual methods. At $H = 16\,820$ , $\sigma_{17^\circ\text{C}} = 217.87$ ; from an experimental study of the laws of approach to absolute saturation as $H$ and $T$ are varied, and by an extrapolation from $H = 18\,550$ and $T = 100^\circ\text{K}$ to $H = \infty$ and $T = 0^\circ\text{K}$ , it was found that $\sigma_\infty = 221.92$ ; hence $\sigma_\infty \times \text{atomic weight} = 12\,390 = 11 \times 1\,126$ that is, the magnetic moment of the Weiss magneton is 1 126, cf. 146.1, Table 19, p. 403, see also p. 345 ( <sup>80</sup> ).
3	Merek. Fused in H. Tabular values have been corrected for thermal expansion, $d_{20} = 7.854\text{ g/cm}^3$ ; $\sigma$ measured for $H = 8\,800$ , $10\,500$ , $12\,400$ , and $13\,500$ , and $\sigma_\infty$ obtained by extrapolating ( $\sigma, H^{-1}$ ) curve to $H = \infty$ ( <sup>53</sup> ).
4	Fused in N in crucible of calcined magnesia. Using $H = 1\,700$ to $20\,000$ , found ( <sup>83</sup> ) $\sigma_{\infty, 20.3^\circ\text{K}} = 1.0175 \sigma_{\infty, 20^\circ\text{C}}$ ; data corrected for thermal expansion ( <sup>83</sup> ). (No other data given.)
6	Fused in vacuum and annealed; $C = 0.0015\%$ .
7	Fused in vacuum and annealed; $C = 0.0017\%$ .
8	Fused in vacuum and annealed; $C = 0.0018\%$ .
10	Fused in vacuum, forged, annealed from $900^\circ\text{C}$ , cooling to $200^\circ\text{C}$ in 48 hr. Before forging, $C = 0.006\%$ ; after, $C = 0.0125\%$ .
13	Annealed from $800^\circ\text{C}$ , $C = 0.012\%$ .

TABLE 6.—(Continued)

Key	Remarks						
15	Plate, $C = 0.024\%$ ; $d = 7.876\text{ g/cm}^3$ ; $\sigma_\infty = 218.4$ after correction for effect of C, Si, Mn; $15_c$ = unannealed, $15_{a1}$ = after first annealing in vacuum ( $800^\circ\text{C}$ for 24 hr), $15_{a11}$ = after 13th annealing ( $830^\circ\text{C}$ ), rapid cooling. After 5th annealing ( $920^\circ\text{C}$ , rapid cooling), $\mu_n(\text{max.}) = 11\,600$ , $H_c = 0.225$ , $B_r = 5\,000$ .						
Key =	6	7	8	10	15 <sub>c</sub>	15 <sub>a1</sub>	15 <sub>a11</sub>
$H$	$B_n$ , Normal induction						
0.2	6 700	2 400	1 500				
0.4	12 900	10 200	9 900				
0.5				6 090	180	7 500	2 350
1	14 600	12 700	14 100	9 500	600	10 240	4 850
2				12 350			
4	15 400	13 900	15 500				
8				15 590			
20	16 400	15 000	16 400	16 200	15 300	16 200	15 850
100	18 400	17 200	18 200	17 950	18 380	18 050	17 700
% C	0.0015	0.0017	0.0018	0.006	0.024	0.024	0.024
$\mu_n(\text{max.})$	41 500	27 300	24 900	12 950	1 850	14 600	4 900
$B_\mu$				6 550			
$B_{\text{max.}}$	10 000	10 000	10 000	15 000	19 710	19 450	18 520
$B_r$				9 940	11 450	10 850	850
$H_c$	0.17	0.21	0.23	0.34	2.83	0.375	0.155
$W$	505	647	735	1 990*			
Lit.	(94)	(94)	(94)	(90)	(22)	(22)	(22)

\* For  $B_{\text{max.}} = 10\,000$ ,  $W = 1\,060$ .

Key =	15 <sub>c</sub>	15 <sub>a1</sub>	15 <sub>a11</sub>
$H$	$\mu_n$ , Permeability ( <sup>22</sup> )		
0.25			4 000
0.5	360	15 000	4 700
0.75	467	12 400	4 867
1.0	600	10 240	4 850
1.5	1 010	7 600	4 733
2.5	1 748	5 120	4 280
5	1 784	2 894	2 900
10	1 285	1 550	1 535
20	765	810	792.5
50	343.0	342.0	334.4
100	183.8	180.5	177.0
150	127.7	125.8	123.5
200	98.58	97.25	
300	68.83	69.00	
500	43.26	43.34	
1 000	22.52	22.57	
2 000	11.81	11.81	
3 000	8.21	8.21	
4 000	6.405	6.405	
4 500	5.802	5.811	
$\mu_n(\text{max.})$	1 850	14 600	4 900
1000 $\eta$	3.08	0.78	
$H_c$	2.8	0.37	0.15
	$B$ , Cyclic induction ( <sup>22</sup> )		
$\pm 200$	$\pm 19\,710$	$\pm 19\,450$	$\pm 18\,520$
$+150$	$+19\,160$	$+18\,870$	$+17\,700$
100	18 510	18 150	16 770
50	17 470	17 230	16 100
25	16 480	16 580	15 520
10	15 240	15 920	15 120
5	14 170	15 320	12 850
2.5	13 200	14 400	



TABLE 6.—(Continued)

Key =	15 <sub>c</sub>	15 <sub>a1</sub>	15 <sub>a12</sub>
H	B, Cyclic induction (22)		
+ 1	12 270	13 020	6 300
0	11 440	10 850	+ 850
- 0.25	11 200	+ 9 400	- 350
- 0.5	10 930	- 6 500	- 1 600
- 0.75	10 620	- 8 900	- 2 700
- 1.0	10 300	-10 000	- 3 850
- 1.5	9 420	-11 400	- 6 000
- 2.5	+ 3 100	-12 800	-10 200
- 5	- 7 770	-14 460	-14 500
- 10	-12 760	-15 500	-15 350
- 20	-15 300	-16 200	-15 850
- 50	-17 150	-17 100	-16 720
-100	-18 380	-18 040	-17 700
-150	-19 160	-18 870	-18 520
B <sub>r</sub>	11 440	10 850	850

13	$\mu_n$ , Permeability (68)								H <sub>m</sub> *
H	0.2	0.5	1	1.5	2	3	10	60	
t									
-190	60	90	100	140	190	430	1130	286	6.9
-121	65	120	250	250	700	1000	1200	284	5.4
- 60	70	190	400	400	1100	1800	1300	283	4.2
+ 23	80	260	500	870	1900	2600	1400	281	2.9
102	100	400	800	2200	3150	3130	1420	280	2.4
203	160	600	1200	4000	4350	3630	1430	275	1.8
308	200	800	1900	5400	4850	3760	1440	270	1.45
403	260	1200	5500	5740	4900	3780	1360	270	1.25
498	425	2600	7000	6140	5160	3830	1320	266	1.00
547	900	4000	7000	6000	5050	3710	1290	265	0.90
596	1200	4400	6800	5300	4950	3610	1290	255	0.85
642	1800	5600	6600	5740	4800	3500	1240	242	0.80
688	2600	6400	6300	5540	5500	3230	1170	220	0.75
724	3200	8400	6100	4800	4050	2950	1040	186	0.44
752	5000	9200	6100	4600	3650	2600	880	153	
781	2400	4200	2800	2140	1700	1260	430	78	

13 (68) (Cycle H = ±90)					3* (53)				
t	W	B <sub>90</sub> †	B <sub>r</sub>	H <sub>c</sub>	t	$\sigma_\infty$	i	$\sigma_\infty$	
-190	26 900	17 600	11 300	4.00	-188	220.9	645	147.7	
-120	24 150	17 600	12 300	3.55	- 78	219.0	656	144.0	
- 60	21 200	17 500	13 200	2.97	+ 16	216.2	662	142.9	
+ 23	17 490	17 400	13 600	2.31	105	213.3	670	137.8	
102	14 320	16 900	13 440	1.93	181	210.4	671	138.8	
203	9 670	16 150	12 920	1.48	265	205.7	679	133.1	
308	7 630	15 960	12 400	1.39	337	200.8	682	131.3	
402	6 990	15 900	11 400	1.32	426	192.2	700	120.5	
498	5 080	15 840	9 930	0.87	499	183.7	718	106.2	
550	4 260	15 640	9 340	0.86	526	179.3	724	105.0	
596	3 420	14 880	8 290	0.83	562	173.4	747	83.5	
640	3 040	14 390	7 860	0.75	603	161.7	751	75.1	
685	2 640	13 050	6 800	0.60	630	154.6	759	62.1	
724	1 610	11 090	5 280	0.44	631	153.7	761	58.8	
752	1 020	8 760	3 470	0.25	632	151.9	769	40.1	
768	564	5 140	1 030	0.14	642	148.1	772	24.0	

\* See also Table 4. † For H = 90.

## Carbon Irons and Steels

## INTRODUCTION

In carbon irons and in carbon-silicon irons, the C may exist in one or more of three states. If the amount is small, the C is in solution; in this form it has a very great effect upon the magnetic properties. In larger amounts, the excess is precipitated as Fe<sub>3</sub>C,

at first in isolated masses of cementite, later as pearlite. In still larger amounts, the excess is precipitated as graphite; as graphite, it has scarcely any effect upon the magnetic properties. Mild steel contains only a small amount of C, and when annealed from about 900°C, the C is in the form of pearlite. Hard steel, or martensite, contains more C. Steel containing 0.85% C is a eutectoid; under suitable heat treatment it forms a material of homogeneous composition; there is no segregation of either ferrite or cementite. For effect of C and of Si upon permeability, see Fig. 13.

The magnetic quality of a material may be expressed by the hysteretic loss ( $W$ ) per cm<sup>3</sup> per cycle of amplitude  $B_{\max}$ . (say,  $B_{\max} = 10\,000$ ), by the coercive force ( $H_c$ ) for  $B_{\max}$ , or by the maximum reluctivity ( $1/\mu_n \max.$ ) (cf. Figs. 12, 13).

*Effect of C and Impurities upon Hysteretic Loss.*—If  $W_i$  refers to the condition of very large grains, and if  $N$  = number of visible grains per mm<sup>2</sup> when the surface is polished and etched, then if all the C is dissolved,  $W = W_i + 65\sqrt{N}$ ; if cementite, pearlite, or graphite is present,  $W = W_i + 3N$ . For a carbon iron, or for a carbon-silicon iron, containing  $C\%$  of C and no other impurity,  $W_i = a + b(C - d)$ , where  $a$ ,  $b$ ,  $d$  depend upon the Si content; see Table 7 and Fig. 11.

TABLE 7.—EFFECT OF C UPON HYSTERETIC LOSS (94)

 $W_i = a + b(C - d)$ ; unit of C, of Si = 1% (v. also Fig. 11)

Si	Range of C	a	b	d	State of carbon
0	0	0.0082	0	100 000 0	Dissolved
	0.01	0.08	850	2 250 0.0085	Dissolved and cementite
	0.10	0.90	1 033	16 500 0.09	Dissolved, cementite, and pearlite
2	0	0.0082	0	100 000 0	Dissolved
	0.01	0.50	900	16 500 0.009	Dissolved and pearlite
4	0	0.0082	0	100 000 0	Dissolved
	0.01	0.079	850	2 250 0.0085	Dissolved and cementite
	0.079	1.0	1 009	0 0	Dissolved, cementite, and graphite
6	0	0.0065	0	100 000 0	Dissolved
	0.01	1.0	700	0 0	Dissolved and graphite

Small amounts of S, Mn, and P increase  $W_i$  by the amounts ( $\Delta W$ ) indicated by the following equations (94), the symbol denoting the percentage of the corresponding element: If Si = 0, and approximately if Si < 2,  $\Delta W = 195 + 18\,000S + 1\,000Mn + 13\,000(P - 0.015)$ , provided  $S \leq 0.10$ ,  $Mn \leq 1.0$ ,  $P \leq 0.015$ ; if  $0.015 < P \leq 0.14$ , the coefficient (13 000) of last term must be replaced by zero. If Si = 4, and approximately if  $4 \leq Si \leq 6$ ,  $\Delta W = 12\,000S + 800Mn - 4\,000P$ . The presence of P is undesirable if Si = 0, but desirable if Si = 4 to 6.

TABLE 8.—COERCIVE FORCE ( $H_c$ ): EFFECT OF C AND QUENCHING TEMPERATURE ( $t_q$ ) (22)

Unit of C = 1% by weight

C	$t_q$	750°C	800°C	850°C	900°C	950°C	1000°C	1100°C
0.068		1.80	2.34	4.48	17.1	15.1	11.7	13.2
0.110		3.72	4.61	3.83	17.9		12.4	15.7
0.155		5.43	8.10	9.15	26.0	25.8	25.0	25.0
0.208		6.74	14.3	25.7	27.1	27.0	26.0	25.5
0.234		7.28	13.2	23.2	21.6	16.5	17.8	19.5
0.445		25.3	35.6	36.7	34.8	35.0	35.0	32.9
0.475		26.8	34.4	34.2	34.2	33.2	32.7	30.6
0.695		37.3	46.8	47.4	47.4	47.3	45.7	41.1
0.708		46.0	46.1	46.2	46.2	45.2	44.5	40.3
0.710		31.6	46.7	46.5	46.8	45.6	44.2	40.4



TABLE 8.—(Continued)

C	$t_d$	750°C	800°C	850°C	900°C	950°C	1000°C	1100°C
0.800		42.5	48.2	47.5	47.0	45.9	44.7	42.2
0.994		48.9	55.6	48.6	46.2	45.8	42.9	41.0
1.105		40.1	60.6	58.2	59.2	55.9	53.8	47.1
1.575		54.0	61.0	61.6	59.7	56.4	44.1	36.4
1.775		52.0	59.7	62.2	67.0	70.1	69.1	47.7

Also (94), if  $C < 0.006$ ,  $H_c = 80C$ ;  $0.006 < C < 0.09$ ,  $H_c = 80C + 0.8(C - 0.006)$ ;  $0.09 < C$ ,  $H_c = 80C + 5.4(C - 0.09)$ ; see Fig. 12.

Cementite (35).— $\text{Fe}_3\text{C}$ ;  $d = 7.07$ ,  $\sigma_m = 135$ ,  $\theta = 215^\circ\text{C}$ .

Pearlite (22).—If the pearlite contains  $p\%$  C,  $d_{\text{red.}} = 7.876 - 0.03p$ ;  $\rho_{\text{red.}} = 10.5 + 3p + 2p^2$  and  $H_c = 0.7 + 7.5p$  if  $p \leq 0.9$ ; if  $p \geq 1$ , for  $\rho$ , and  $> 0.9$ , for  $H_c$ , the increase is less rapid than is indicated by equation.  $4\pi I_{\infty(\text{red.})} = 21\,620 - 1\,580p$  if  $p < 0.96$ ,  $= 20\,100 - 930p$  if  $p > 0.96$ ; from  $B_{\text{max.}} = 20\,000$ ,  $B_r$  varies unsystematically around 10 000.

Martensite (22).—(1) Quenched at 850°C. If  $p_d\%$  of dissolved C and  $p_c\%$  of C in form of cementite,  $d_{\text{red.}} = 7.876 - 0.14p_d - 0.03p_c$ ,  $\rho_{\text{red.}} = 10.3 + 1.6p_d + 3p_c + 23p_d^2 + 2p_c^2$  if  $p_c \leq 0.9$ , if  $p_c \geq 1$ , the increase is less rapid. If  $p (= p_c + p_d) < 1.2$ ,  $4\pi I_{\infty(\text{red.})} = 21\,620 - 3\,200p$ ; if  $p > 1.2$ , the decrease is less rapid; for aged material,  $1\,000\beta = -0.63 + 0.42p$ ,  $\beta = 0$  if  $p = 1.5$ . (2) Quenched at 1100°C.  $d_{\text{red.}} = 7.876 - 0.08p$  if  $p < 1$ ;  $\rho_{\text{red.}} = 10.3 + 9.3p + 7.4p^2$  if  $p < 1.8$ ;  $4\pi I_{\infty(\text{red.})} = 21\,620 - 2\,060p$  if  $p < 1.1$ ; for aged material,  $1\,000\beta = -0.50 + 0.34p$ .

TABLE 9.—ANNEALED CARBON IRONS: PRINCIPAL MAGNETIC CONSTANTS

$\kappa_n^{-1} = a + bH$  if  $H$  is great;  $a$  derived from observations at  $H \leq 1000$  gauss; for composition, see Table 1

Key	% C	$t_d$	$B_{\text{max}}$	$B_r$	$H_c$	$\mu_n(\text{max.})$	$I_{\infty}$	$a$
$H_{\text{max.}} = 150$ gauss [(11), except 43 (64)]								
14	0.018	930	18 740	11 680	3.1	5 320	1 703	0.0104
31	0.14	930	18 240	9 980	3.3	2 990	1 722	0.0232
35	0.23	870	18 010	10 010	4.5	2 090	1 688	0.0133
36	0.32	870	17 790	9 830	5.0	1 560	1 670	0.0147
40	0.52	820	17 310	9 410	6.1	1 180	1 626	0.0186
43	0.85		15 260	11 100	6.9			
44	0.88	760	16 050	10 610	8.5	830	1 583	0.0316
51	1.28	760	15 130	10 730	8.3	880	1 537	0.0530
52	1.32	760	14 990	10 530	7.5	920	1 507	0.0431
55	1.55	760	14 190	9 390	7.5	900	1 528	0.0579
57	1.60	760	13 850	8 990	11.0	470	1 534	0.0537
$H_{\text{max.}} = 150$ gauss [(22); except 68, $H_{\text{max.}} = 200$ (23)]								
16	0.027		18 850	9 850	0.76	6 400	1 683	
18	0.044		19 100	11 050	0.37	14 800	1 704	
28	0.085		18 620	10 250	0.885	5 700	1 702	
34	0.23	930	18 050	10 600	2.35	2 180	1 664	
41	0.69	930	17 000	11 100	6.29	880	1 615	
47	0.99	930	16 440	9 950	7.50	660	1 592	
56	1.57	930	15 000	10 300	10.23	530	1 550	
59	1.78	930	14 500	10 000	12.52	415	1 517	
66	3.109		11 920	5 300	4.6	620	1 333	

TABLE 10.—QUENCHED AND DRAWN CARBON IRONS: PRINCIPAL MAGNETIC CONSTANTS (11)

$\kappa_n^{-1} = a + bH$  if  $H$  is great;  $a$  derived from observations at  $H \leq 1000$  gauss; for material and impurities, see Table 1; see also Figs. 14, 15, 16 and Table 11.

$t_d$	$B_{\text{max.}}^*$	$B_{\text{max.}}^\dagger$	$B_r^\dagger$	$H_c^\dagger$	$\mu_n(\text{max.})$	$I_{\infty}$	$a$	$\frac{B_r H_c^\dagger}{1000}$
36, 0.32 % C; quenched at 900°C; drawn to $t_d$ , °C (2 specimens)								
†	16 470	21 450	12 950	18	333	1 660	0.014	386.5
100	16 240	21 200	12 300	21	317	1 610	0.016	445.5
170	16 290	21 250	12 550	19.5	339	1 640	0.015	414.5
230	16 790	21 520	13 520	19	38.1	1 650	0.010	408.
270	17 030	21 790	13 550	16	462.5	1 674	0.010	348.2
350	17 300	21 540	14 100	15	472	1 660	0.011	323.2
450	17 350	21 440	15 300	14				
500	16 750	21 000	15 060	14	551	1 620	0.014	294
700	16 780	20 940	15 000	8	915	1 616	0.020	167.5
†	16 040	21 680	12 860	20	290	1 676	0.015	433.6
150	16 570	21 660	12 840	15	346	1 670	0.015	325
200	16 510	21 440	12 900	21	354	1 658	0.015	451
250	17 050	21 740	13 100	16	388	1 674	0.015	348
300	17 170	21 520	13 420	16	425	1 650	0.011	344.6
400	17 270	21 540	14 710	16	477	1 660	0.010	345
470	17 250	21 440	15 100	16	514	1 660	0.015	343.2
600	17 230	21 490	15 350	10	834	1 660	0.014	214.9
37, 0.39 % C; quenched at 800°C; drawn to $t_d$ , °C								
†	16 120	21 630	12 450	19	303.5	1 670	0.015	411.5
150	15 850	20 940	12 000	16	306	1 746	0.028	335.3
200	16 310	21 440	12 500	20.5	332	1 660	0.017	440
250	16 950	21 740	12 800	18.5	370	1 668	0.018	402.5
300	17 130	21 740	13 340	18	400	1 680	0.012	391.5
400	17 180	21 420	14 360	16	458	1 650	0.011	343
470	17 080	21 340	14 940	18	452	1 660	0.012	384
600	16 950	21 460	15 080	10	656	1 680	0.020	214.6
44, 0.88 % C; quenched at 800°C; drawn to $t_d$ , °C (2 specimens)								
†	7 990	17 100	7 700	56	80	1 446	0.100	958
100	9 870	18 100	8 100	43	107	1 500	0.070	778.4
170	8 510	17 050	7 710	48	86.5	1 410	0.089	819
230	12 950	19 720	10 220	41	158.5	1 540	0.082	809
270	15 400	21 040	10 900	27	266	1 680	0.020	568.3
350	16 830	20 730	13 780	24	319.5	1 596	0.011	498
450	16 290	20 420	14 580	30	262	1 590	0.020	611.5
500	15 530	19 820	14 480	28	276	1 550	0.028	556
700	15 450	19 840	13 800	14	521.5	1 560	0.020	278
†	8 000	17 080	7 700	54	80.5	1 440	0.095	923
150	8 130	16 840	7 500	56	81.5	1 414	0.098	944
200	7 300	17 140	8 000	51	85.7	1 408	0.078	874
250	14 080	20 340	11 000	39	182	1 580	0.025	794
300	16 450	20 660	13 120	27.5	292	1 596	0.011	502
400	16 550	20 340	14 060	30	389	1 576	0.016	611
470	15 850	20 140	14 600	32	262	1 562	0.016	645
600	15 540	20 020	14 280	20.5	368	1 573	0.022	411
45, 0.96 % C; quenched at 800°C; drawn to $t_d$ , °C								
†	8 990	17 780	7 900	44	93.4	1 510	0.103	783
100	6 800	16 490	7 350	47	67.5	1 390	0.090	775.8
170	8 200	15 490	6 750	44	86.6	1 270	0.081	683
230	12 250	18 690	9 150	36	153	1 470	0.038	673
270	13 600	19 240	9 900	31	202	1 510	0.027	596
350	14 900	19 640	11 740	32	240	1 526	0.023	623.5
450	14 550	19 240	12 500	34	199	1 520	0.040	654
500	14 180	18 740	12 800	29.5	255	1 468	0.032	553.5
700	13 880	18 360	12 220	15.5	390	1 450	0.038	285

\* Cyclic;  $H_{\text{max.}} = 100$  gauss.

† Cyclic;  $H_{\text{max.}} = 1000$  gauss.

‡ Not drawn.



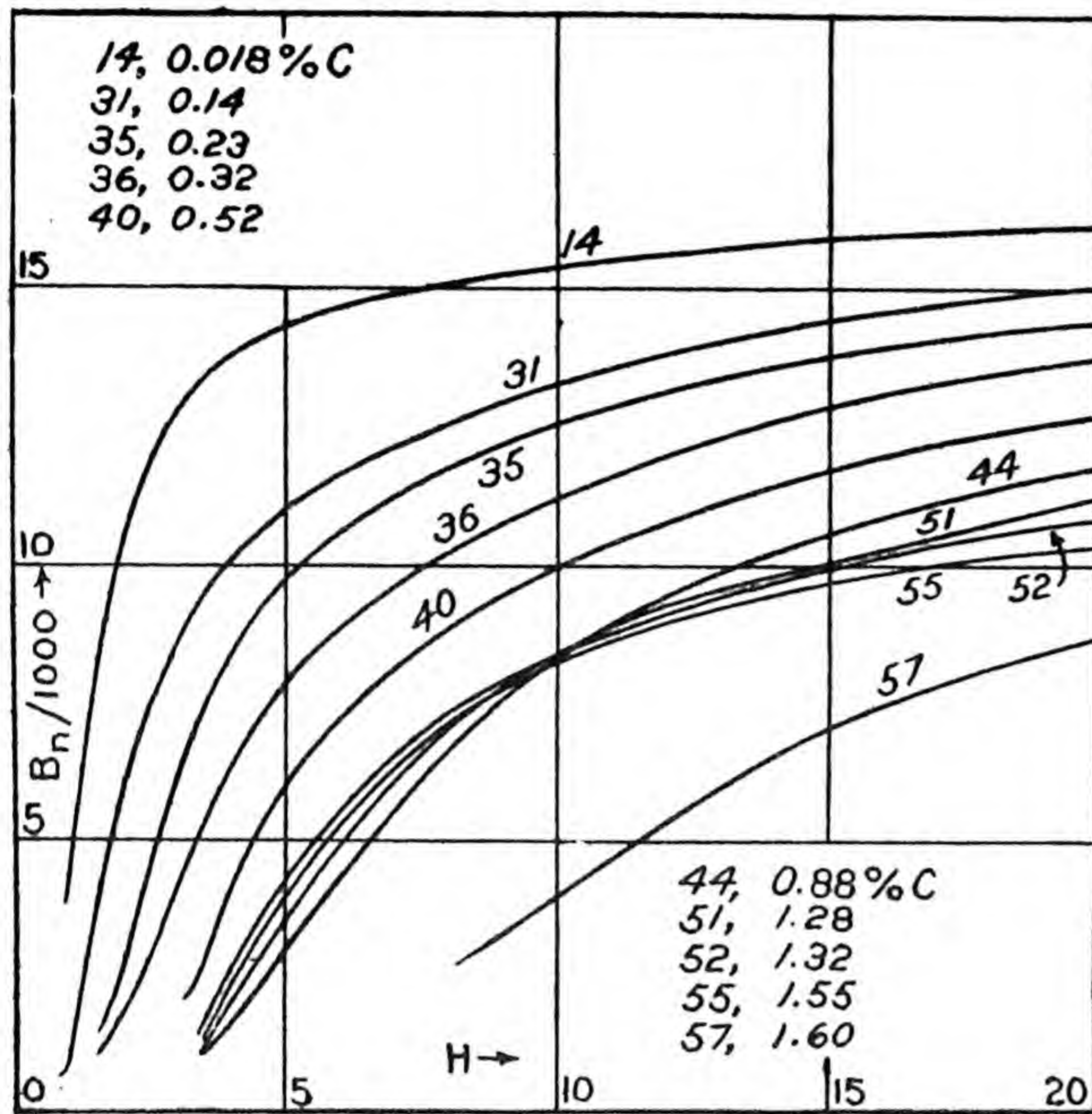


FIG. 14.—Effect of C upon normal induction (11). Specimens annealed in vacuum. On the curves are the key numbers (Table 1) of the materials.

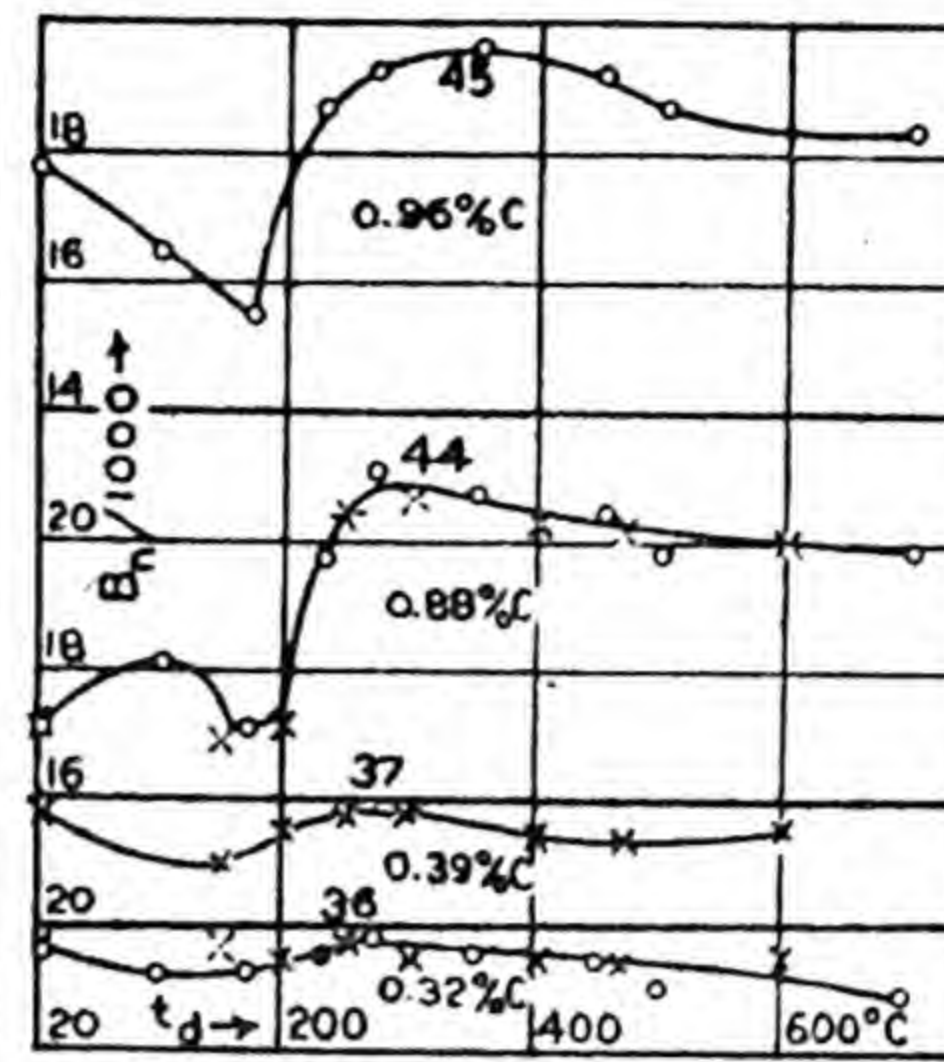


FIG. 15.—Effect of drawing temperature ( $t_d$ ) upon normal induction (11).  $H_{max.} = 1000$ . On the curves are the key numbers (Table 1) of the materials. Quenching temperature =  $t_q$ ; for 36,  $t_q = 900^\circ\text{C}$ ; 37,  $t_q = 850^\circ\text{C}$ ; 44, 45,  $t_q = 800^\circ\text{C}$ .

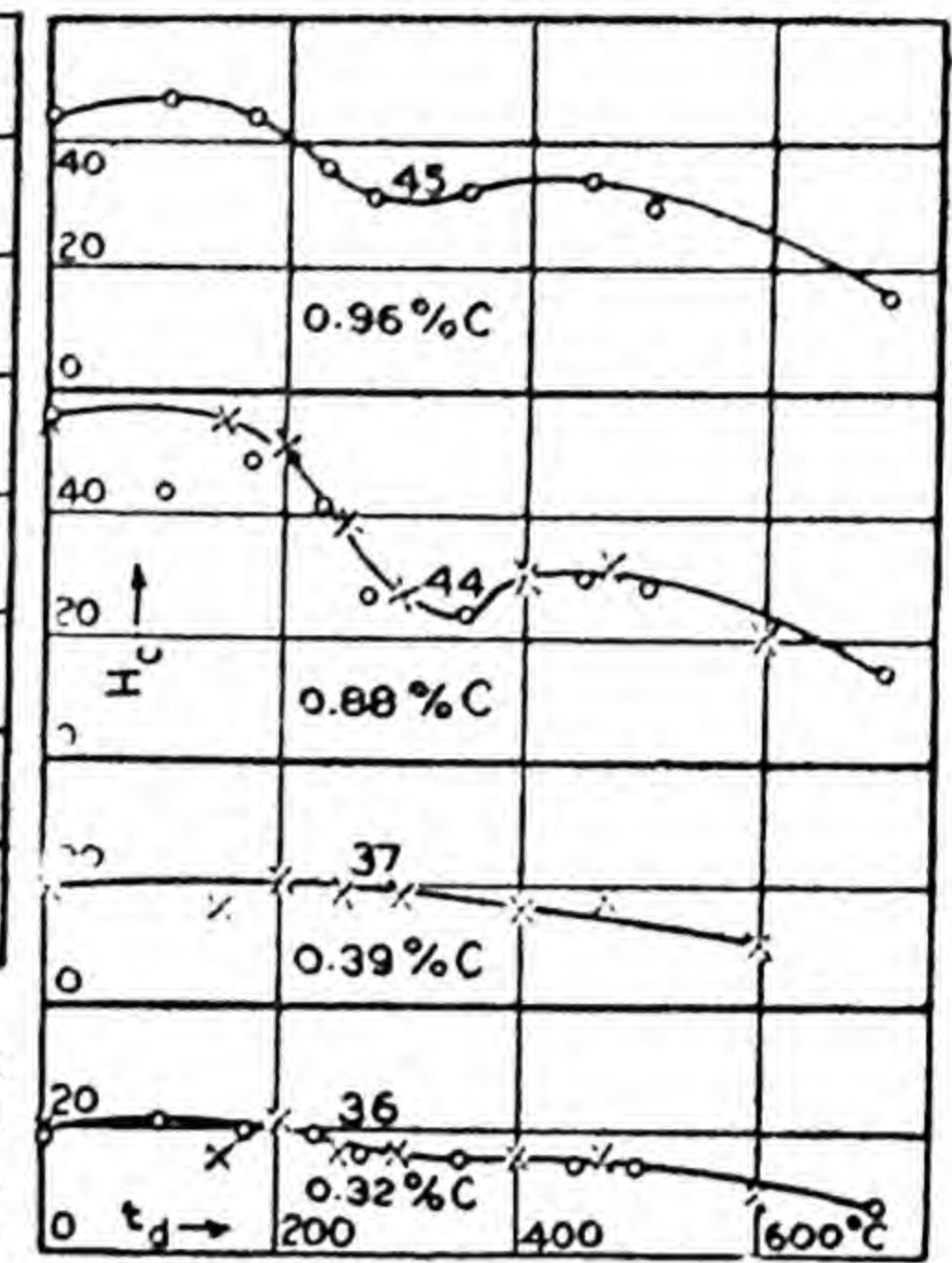


FIG. 16.—Effect of drawing temperature ( $t_d$ ) upon coercive force (11). Conditions as for Fig. 15, *q.v.*

TABLE 11.—NORMAL AND CYCLIC MAGNETIZATION OF CARBON IRONS: VARIOUS HEAT TREATMENTS  
For material and impurities, see Table 1;  $t_a = 900^\circ\text{C}$ , except as indicated

Key	16 <sub>c</sub>	16 <sub>a</sub>	18 <sub>c</sub>	18 <sub>a</sub>	28 <sub>c</sub>	28 <sub>a</sub>
$H$	$\mu_n$ , Normal permeability (22)					
0.25	1 200	1 240	960	12 400	1 400	1 800
0.5	1 800	2 000	1 200	14 200	2 600	3 100
0.75	3 000	4 530	1 530	11 920	4 140	4 940
1.0	5 000	6 350	2 300	10 200	4 600	5 650
1.5	5 330	5 600	4 030	7 820	4 200	5 460
2.5	4 200	4 220	3 720	5 370	3 360	4 320
5	2 580	2 590	2 430	3 000	2 210	2 710
10	1 460	1 460	1 410	1 570	1 330	1 500
20	785	810	775	805	740	785
50	340	340	335	340	330	335
100	179	181	180	183	175	178
150	124.7	125.7	125.0	127.3	122.7	124.1
300	67.3	67.3	68.0	68.1	66.7	67.3
500	42.4	42.3	42.9	42.9	42.2	42.8
1 000	22.12	22.04	22.35	22.32	22.10	22.34
2 000	11.60	11.57	11.70	11.69	11.61	11.69
3 000	8.07	8.06	8.14	8.14	8.08	8.14
4 500	5.71	5.71	5.76	5.76	5.72	5.76
	$B$ , Cyclic induction (22)					
150	18 700	18 850	18 750	19 100	18 400	18 620
100	17 970	18 130	18 000	18 300	17 600	17 800
50	17 030	17 220	17 000	17 120	16 500	16 800
25	16 240	16 530	16 070	16 430	15 600	16 070
10	15 300	15 700	14 930	15 850	14 600	15 350
5	14 500	14 220	14 040	15 500	13 300	14 740
2.5	13 700	12 920	13 000	15 100	11 900	13 740
+ 1	12 700	11 600	11 900	13 700	10 160	12 300
0	10 400	9 850	10 600	11 050	7 850	10 250
0.25	10 850	8 950	10 150	+ 9 400	6 800	9 500
0.5	10 200	7 100	9 630	- 6 300	4 700	8 250
75	9 200	+ 1 000	9 000	- 9 000	+ 1 200	+ 4 400



## INTERNATIONAL CRITICAL TABLES

TABLE 11.—(Continued)

Key	16 <sub>c</sub>	16 <sub>a</sub>	18 <sub>c</sub>	18 <sub>a</sub>	28 <sub>c</sub>	28 <sub>a</sub>
<i>H</i>	<i>B</i> , Cyclic induction (22)					
— 1.0	+ 3 500	— 5 400	+ 8 100	—10 200	— 2 300	— 1 900
— 1.5	— 7 050	— 8 200	— 1 500	—11 730	— 5 000	— 6 450
— 2.5	—10 400	—10 500	— 8 560	—13 400	— 7 600	—10 130
— 5	—12 900	—12 940	—11 940	—15 000	—10 630	—13 360
— 10	—14 600	—14 630	—14 020	—15 680	—13 180	—14 880
— 20	—15 700	—16 100	—15 450	—16 130	—14 760	—15 680
— 50	—16 900	—17 120	—16 830	—17 100	—16 300	—16 700
—100	—17 930	—18 130	—17 980	—18 280	—17 520	—17 770
—150	—18 700	—18 850	—18 750	—19 100	—18 400	—18 620
<i>B<sub>r</sub></i>	11 400	9 850	10 600	11 050	7 850	10 250
<i>H<sub>c</sub></i>	1.06	0.76	1.46	0.37	0.83	0.885
$\mu_n(\text{max.})$	5 400	6 400	4 200	14 800	4 600	5 700
1000 $\alpha$	1.31	1.05	1.57	0.54	1.62	1.10
$\frac{1}{2}\pi I_{\text{red.}}$	21 200	21 180	21 419	21 419	21 249	21 400

$24I^* (65); \mu_n$				$24I^* (65); I$ , Cyclic magnetization					
<i>H</i>	$\mu_n$	<i>H</i>	$\mu_n$	<i>H</i>	$4\pi I$	<i>H</i>	$4\pi I$	<i>H</i>	$4\pi I$
0.14	1 200	1.91	6 410	±164.5	±19 100	—0.22	+5 800	— 0.77	— 5 010
0.23	3 020	3.67	3 740	+106.8	+18 260	—0.36	2 540	— 0.87	— 6 820
0.30	5 300	7.79	1 920	71.8	17 600	—0.41	1 280	— 1.08	— 8 720
0.36	7 000	20.7	770	37.3	16 730	—0.45	370	— 1.42	—10 760
0.41	8 090	71.2	248	20.7	16 120	—0.50	— 470	— 1.91	—12 210
0.54	9 560	106.8	172	7.32	15 230	—0.53	— 970	— 3.54	—13 730
0.73	9 500	164.5	117	2.10	14 300	—0.56	—1 360	— 7.80	—14 920
0.97	9 120	260.1	78.0	0.28	11 790	—0.60	—2 310	—20.7	—15 980
1.38	7 820	322.2	64.4	— 0.09	8 890	—0.67	—3 390	—71.7	—17 570

\* For anhysteretic magnetization and differential permeability, see Table 2.

Key	34	41	47	56
<i>t<sub>a</sub></i>	930°	930°	930°	930°
<i>t<sub>q</sub></i>	850°	850°	850°	850°
<i>H</i>	$\mu_n$ , Normal permeability (22)			
1.0	1 000	280	200	
1.5	1 600			
2.5	2 200	340	230	210
5	1 840	740	370	270
10	1 200	850	655	500
20	710	600	530	470
50	320	290	280	250
100	172.0	160.8	155.0	141.3
150	120.3	113.3	109.6	100.0
200	93.0	87.3	85.0	77.0
300	65.2	61.6	59.7	53.3
500	41.4	39.2	38.0	34.1
1 000	21.75	20.75	20.23	18.55
2 000	11.45	11.03	10.82	10.18
3 000	7.97	7.73	7.61	7.24
4 000	6.23	6.06	5.98	5.72
4 500	5.65	5.50	5.42	5.21
5 500				
6 500				
<i>B</i> , Cyclic induction (22)				
+300		19 280	17 200	14 250
200		18 220	16 120	12 870
150	18 050	17 500	15 330	11 910
100	17 300	16 540	14 200	10 720
50	16 200	15 100	13 660	9 120
25	15 370	13 860	11 600	8 080
10	14 270	12 750	10 730	7 300
5	13 300	12 280		
2.5	12 450	11 900		



TABLE 11.—(Continued)

TABLE 11.—(Continued)

Key	34		41		47		56	
$t_a$	930°		930°		930°		930°	
$t_d$	850°		850°		850°		850°	
$H$	$B$ , Cyclic induction (22)							
+ 1	11 600		11 450		10 270			
0	10 600	11 600	11 100	10 000	9 950	6 700	10 300	6 650
— 1.0	9 000		10 650		9 520			
+ 1.5	+ 8 000							
2.5	— 2 400		9 500		8 800		9 700	
5	— 8 600	10 880	+ 4 800	9 620	+ 6 800		8 650	
10	—11 950	9 650	— 7 300	9 200	— 4 650	6 000	+ 900	6 100
20	—14 100	+ 3 600	—11 950	+ 8 220	—10 600	+ 5 080	— 8 800	5 450
50	—15 970	—13 450	—14 600	— 3 300	—13 850	— 400	—12 570	+ 2 600
75	—16 650	—15 220	—15 500	—11 100	—14 820	— 6 300	—13 500	— 3 700
100	—17 200	—16 150	—16 080	—13 200	—15 500	— 9 100	—14 130	— 7 580
150	—18 050	—17 300	—17 000	—14 900	—16 440	—11 450	—15 000	—10 020
200		—18 140		—15 860		—12 670		—11 200
300		—19 280		—17 200		—14 250		—12 650
$B_r$	10 600	11 600	11 100	10 000	9 950	6 700	10 300	6 650
$H_c$	2.35	23.2	6.29	47.4	7.50	48.6	10.23	61.6
$\mu_n(\text{max.})$	2 180		880		660		530	
$\mu_0$	170	76	126	54	132		143	
$4\pi I_{\text{obs.}}$	20 900	20 770	20 220	19 450	19 860	18 220	19 300	16 710
$4\pi I_{\text{red.}}$	20 970	21 040	20 340	19 770	20 060	18 420	19 530	16 940
$\rho_{30}$	10.95	12.75	13.21	21.17	15.57	34.74	16.53	39.57
$1000\alpha_{\text{red.}}$	5.56	4.75	4.95	3.03	4.35	1.70	4.25	1.58
$d_{\text{red}}$	7.858		7.843		7.848	7.747	7.828	7.743

43† $B_n$ , Normal induction (47)

$H$	$t_d$	20°C†	100°C	170°C	200°C	230°C	250°C	270°C	300°C
20		700	900	1 300	1 200	1 550	2 350	2 350	2 650
50		3 250	3 300	4 850	5 850	9 600	12 750	12 920	14 000
100		8 950	8 900	10 450	11 400	14 370	16 300	14 950	16 630
150		11 380	11 450	12 520	13 230	15 900	17 450	17 120	17 700
200		12 750	12 700	13 630	14 220	16 850	18 150	17 700	18 250
300		14 050	13 950	14 900	15 320	17 950	19 100	18 350	18 850
500		15 550	15 550	16 050	16 660	19 460	20 200	19 380	19 650
700		16 500	16 550	16 850	17 420	20 220	20 700	19 750	20 150
1 000		17 450	17 500	17 650	18 250	20 850	21 250	20 200	20 700
1 500		18 580	18 550	18 620	19 150	21 630	22 000	20 900	21 400
2 000		19 350	19 380	19 400	19 900	22 280	22 600	21 420	21 950
2 500		20 000	20 100	20 100	20 600	22 800	23 150	21 920	22 400

$H$	$t_d$	350°C	400°C	430°C	450°C	470°C	500°C	600°C	700°C
20		3 550	3 550	3 550	2 850	2 750	3 350	4 000	7 100
50		14 350	14 450	14 650	14 250	13 850	13 950	13 650	14 050
100		16 560	16 580	16 800	16 600	16 450	16 250	15 870	15 700
150		17 400	17 550	17 650	17 400	17 420	17 120	16 800	16 450
200		18 000	18 050	18 150	18 100	18 000	17 700	17 300	16 950
300		18 900	18 650	18 800	19 100	18 750	18 550	18 000	17 600
500		19 400	19 400	19 500	19 250	19 180	19 300	18 900	18 700
700		19 900	19 880	20 000	19 900	19 650	19 720	19 400	19 250
1 000		20 360	20 400	20 500	20 400	20 120	20 250	20 020	19 850
1 500		21 050	21 100	21 200	21 100	20 850	21 000	20 700	20 680
2 000		21 660	21 650	21 750	21 650	21 500	21 620	21 450	21 350
2 500		22 250	22 120	22 200	22 150	22 050	22 200	22 050	21 950

43‡ $B_n$ , Normal induction (47)

$H$	$t_d$	20°C†	102°C	170°C	200°C	230°C	250°C	270°C	300°C
20		780	700	840	950	2 200	3 800	2 400	3 700
50		3 180	3 050	3 550	5 350	9 900	13 650	13 400	14 350
100		9 150	8 750	9 000	11 600	14 360	16 600	16 580	16 900
150		11 500	11 250	11 200	13 500	15 900	17 820	17 830	18 000
200		12 700	12 450	12 370	14 600	16 500	18 500	18 500	18 570

† Oil-quenched at 800°C. ‡ Undrawn. § Water-quenched at 800°C.



TABLE 11.—(Continued)  
 $43\frac{1}{2}B_n$ , Normal induction (47).—(Continued)

$H$	$t_d$	20°C†	102°C	170°C	200°C	230°C	250°C	270°C	300°C
300		14 250	14 000	13 700	15 600	17 900	19 300	19 300	19 300
500		15 700	15 750	15 250	16 800	18 940	20 100	20 100	19 900
700		16 700	16 700	16 050	17 500	19 500	20 500	20 600	20 300
1 000		17 650	17 700	16 850	18 250	20 100	21 000	21 100	20 800
1 500		18 800	18 800	17 800	19 150	20 900	21 800	21 800	21 500
2 000		19 600	19 650	18 600	19 800	21 500	22 400	22 300	22 100
2 500		20 250	20 300	19 250	20 400	22 000	22 800	22 800	22 600

$H$	$t_d$	370°C	410°C	450°C	475°C	500°C	600°C	700°C
20		3 500	3 900	3 000	2 600	1 550	7 500	7 000
50		14 350	15 000	14 250	13 450	12 650	14 100	13 350
100		16 900	17 050	16 800	16 500	16 070	16 200	15 100
150		17 700	18 000	17 600	17 500	17 080	17 170	15 900
200		18 200	18 500	18 080	18 000	17 650	17 620	16 400
300		19 000	19 100	18 800	18 800	18 450	18 250	17 100
500		19 500	19 750	19 500	19 700	19 250	19 150	18 000
700		19 950	20 200	19 900	20 100	19 720	19 700	18 600
1 000		20 380	20 700	20 400	20 570	20 300	20 300	19 200
1 500		21 050	21 400	21 100	21 200	21 000	21 000	20 000
2 000		21 650	21 950	21 400	21 700	21 600	21 650	20 700
2 500		22 220	22 400	21 900	22 130	22 120	22 250	21 200

$43\frac{1}{2}$ (47)		$43\frac{1}{2}$ (64)				$43\frac{1}{2}$ (64)			
$H$	$B_n$	$H_{max.}$	$B_{max.}$	$B_r$	$H_c$	$H_{max.}$	$B_{max.}$	$B_r$	$H_c$
14	540	42	2 720	950	9	32	12 080	7 500	5.0
30	1 320	86	8 050	4 540	22	92	15 020	10 980	6.5
56	3 880	137	11 210	6 900	34	120	15 570	11 650	9.0
88	8 040	190	12 680	7 600	44.5	183	16 280	12 100	10.0
118	10 220	220	13 160	7 700	46.0	246	16 990	12 500	10.5
156	11 700	304	14 360	8 150	49.5	325	17 690	13 000	11.0
232	13 250	410	15 240	8 300	50.0	418	18 140	12 620	11.5
318	14 400	485	15 690	8 440	50.5	500	18 380	13 100	12.0
430	15 320	570	16 290	8 550	52.0	680	18 970	13 240	12.0
535	15 960	670	16 580	8 600	52.0	850	19 380	13 480	12.5
685	16 660	748	16 660	8 600	52.0	1 080	19 820	13 600	14.0
860	17 300	842	17 220	8 750	52.0	1 260	20 350	13 650	12.5
1 090	17 900	920	17 420	8 800	53.0	1 520	20 890	14 050	13.0
1 380	18 570	1 050	18 040	8 900	52.5	1 840	21 240	14 000	13.0
1 710	19 100	1 310	18 570	9 000	52.5	2 090	21 930	14 310	13.0
2 000	19 520	1 500	18 750	9 100	53.0	2 300	21 940	14 300	13.0
2 420	20 150	1 710	19 000	9 120	52.5	2 430	21 860	14 200	13.0
2 630	20 440	2 000	19 540	9 300	52.5				
		2 290	19 930	9 380	52.0				
		2 420	19 970	9 300	52.5				

‡ Water-quenched at 800°C. || Oil-quenched at 800°C.

59 (22)				68 (22)				
$t_a$	930°			$H$	Unannealed		Annealed	
$t_g$		850°	1100°		$B_n$	$\mu_n$	$B_n$	$\mu_n$
$H$	$\mu_n$							
2.5	150			2.5	235	94	900	360
5	190			5	570	114	2 950	590
10	325			10	1 960	196	5 150	515
20	405			20	4 700	235	6 820	340
50	240			50	7 520	150	8 620	172
100	135.4			100	9 320	93.2	9 950	99.5
150	96.7			150	10 500	70.0	11 020	73.6
200	75.0			200	11 430	57.2	11 920	59.6
300	53.0			300	12 550	41.8	12 800	42.7
500	33.9	26.7	21.5	500	13 900	27.8	14 130	28.3



TABLE 11.—(Continued)

59 (22)				68 (22)				
$t_a$	930°			$H$	Unannealed		Annealed	
$t_q$		850°	1100°		$B_n$	$\mu_n$	$B_n$	$\mu_n$
$H$		$\mu_n$						
1 000	18.40	15.32	12.60	1 000	15 900	15.9	16 200	16.2
2 000	10.09	8.70	7.28	2 000	17 840	8.92	18 120	9.06
3 000	7.17	6.27	5.32	3 000	19 180	6.39	19 490	6.50
4 000	5.65	5.00	4.28	4 000	20 350	5.09	20 670	5.18
4 500	5.15	4.57	3.93	4 500	20 870	4.65	21 200	4.72
5 500		3.94		5 500	21 920	4.0	22 260	4.06
6 500		3.49		6 500	22 920	3.53	23 250	3.58

$B$ , Cyclic induction				$B$ , Cyclic induction			
300		12 600	6 530	200	11 430		11 920
200		11 520	5 760	150	10 570		11 080
150	14 500	10 800	5 300	100	9 520		10 020
100	13 800	9 870	4 730	50	8 220		8 750
50	12 780	8 630	3 950	25	7 180		7 820
25	11 950	7 820	3 500	10	6 170		6 800
10	11 100	7 250	3 110	+ 5	5 700		6 200
5	10 700			0	5 100		5 300
+ 2.5	10 400			- 2.5	4 670		+ 4 450
0	10 000	6 820	2 800	- 5	4 180		- 1 800
- 5	8 740			- 10	+ 1 750		- 5 150
- 10	+ 4 650	6 270	2 480	- 20	- 4 160		- 6 820
- 20	- 6 900	5 660	+1 950	- 50	- 7 380		- 8 620
- 50	-11 820	+ 2 700	- 440	-100	- 9 200		- 9 950
- 75	-12 920	- 3 450	-2 400	-150	-10 500		-11 020
-100	-13 540	- 7 300	-8 600	-200	-11 430		-11 920
-150	-14 500	-10 020	-4 830				
-200		-11 200	-5 580				
-300		-12 600	-6 530				
$B_r$	10 000	6 820	2 800	$B_r$	5 100		5 300
$H_c$	12.52	62.2	47.7	$H_c$	11.4		4.6
$\mu_n(\text{max.})$	415			$\mu_n(\text{max.})$	240		620
$\mu_0$	95	37		1000 $\eta$	11.4		4.37
$4\pi I_{\infty \text{obs.}}$	19 000	16 460	12 110	$4\pi I_{\infty \text{obs.}}$	16 420		16 750
$4\pi I_{\infty \text{red.}}$	19 100	16 760	12 410				
$\rho_{20}$	17.61	41.65	48.58				
1000 $\alpha_{\text{red.}}$	4.17	1.54	1.87				
$d_{\text{red.}}$	7.799	7.720	7.730				

## Magnet Steels

## INTRODUCTION

The special magnet steels and those other steels which possess similar properties include: Carbon steels **26, 33, 39, 42, 46, 50, 53, 54, 58**; manganese steel **70**; cobalt steels **80 to 85, 87 to 90**; molybdenum steels **91 to 94**; nickel steel **101**; and tungsten steels **136 to 144**. For composition and designation, see Table 1.

For cobalt-manganese steels,  $H_c$  is great and is a maximum for Mn = 4 to 5%; it increases with % Co. An addition of 5% Cr increases  $H_c$ , makes the material very hard so that it becomes saturated only in intense fields (25). For the "K.S." steel (84) containing W,  $H_c$  is very great. Best quenching temperature is 950°C; best quenching bath is a heavy oil. Within the range of composition stated in Tables 1, 13, the magnetic properties do not vary greatly with the composition. For example, four specimens of different composition gave, respectively, for  $H_{\text{max.}} = 1500$ ,  $I_r = 920, 841, 828$ , and  $620$ ,  $H_c = 226, 221, 245$ , and  $257$ . For bars, length =  $l$ , diameter =  $d$ ,  $I_r$  is independent of  $l/d$  if  $l > 20d$ , see Fig. 17 (33).

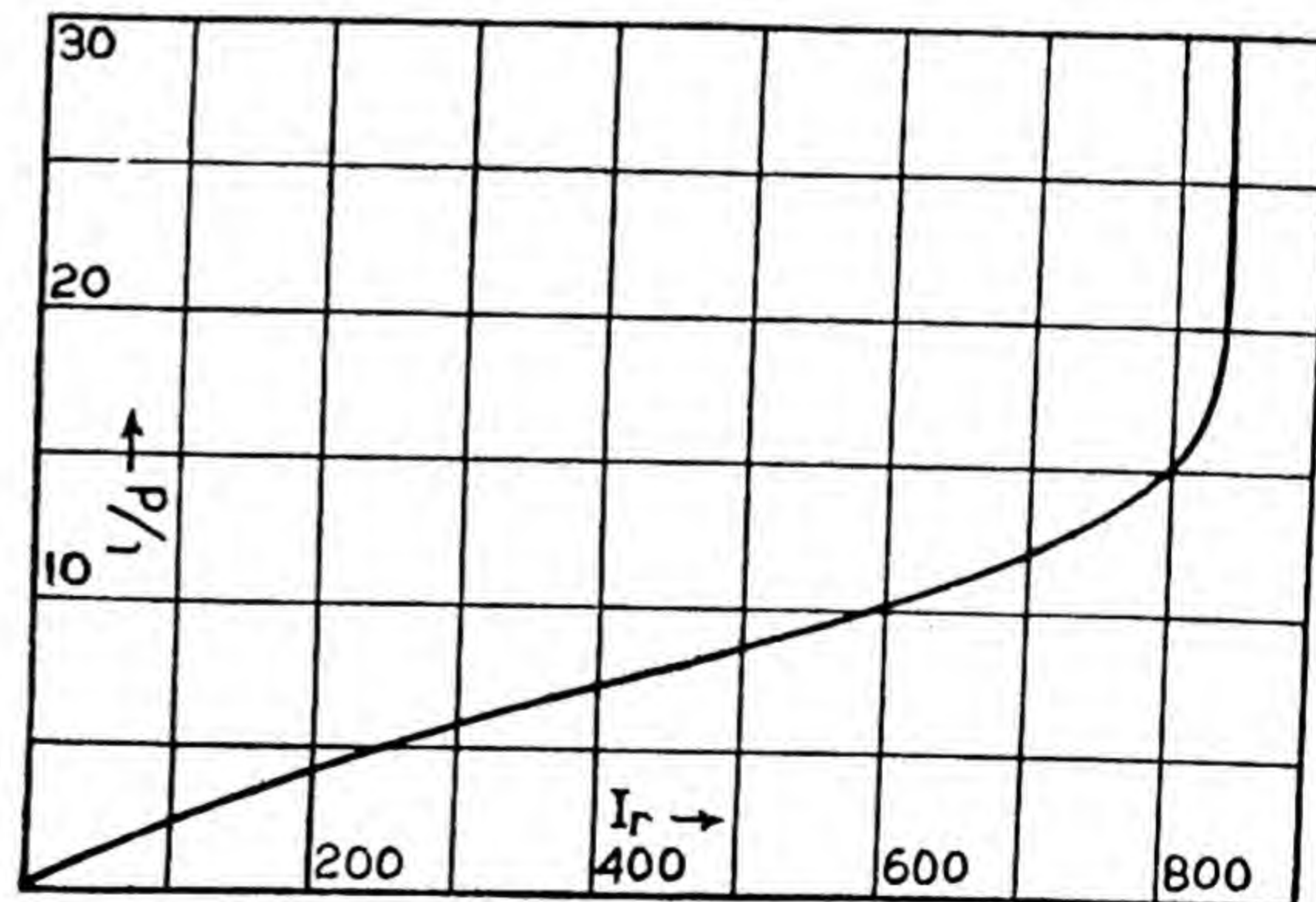


FIG. 17.—Residual magnetization of circular bars: Variation with length ( $l$ ) and diameter ( $d$ ) (33). Material is 84, K. S. magnet steel.



TABLE 12.—CYCLIC MAGNETIZATION

For composition, see Table 1  
Rings\* (1<sup>5</sup>); see also Figs. 18, 19

<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
26 <sub>q</sub>		33 <sub>q</sub>		39 <sub>q</sub>		42 <sub>q</sub>		42 <sub>q</sub>	
505	1 560	505	1 590	515	1 525	515	1 230	505	1 155
256	1 495	490	1 580	510	1 520	268	1 070	245	1 070
167	1 440	248	1 500	260	1 425	160	990	134	965
78.5	1 330	162	1 450	167.5	1 365	+ 78.6	850	+ 75	875
42	1 220	+ 76.8	1 320	+ 79.3	1 230	0	605	0	670
+ 16.1	980	0	770	0	835	- 33.3	370	- 16.7	595
0	625	- 4.2	460	- 13.9	360	- 46.3	150	- 26.7	535
- 1.8	480	- 6.9	+ 64	- 16.7	+ 137	- 51.7	+ 11.3	- 43.0	370
- 2.5	293	- 7.7	- 36.5	- 19.6	- 14.5	- 58.6	- 192	- 48.5	260
- 2.9	113	- 11.4	- 340	- 28.8	- 350	- 78.5	- 580	- 53.3	140
- 3.2	+ 0.8	- 23.6	- 825	- 46.5	- 875	- 135	- 880	- 57.6	+ 22.1
- 3.5	- 36	- 56.0	- 1 200	- 82.5	- 1 150	- 254	- 1 080	- 58.1	- 3.7
- 4.2	- 181	- 84.5	- 1 300	- 136.5	- 1 285	- 505	- 1 230	- 74.7	- 442
- 5.5	- 350	- 120.5	- 1 350	- 260	- 1 400	- 515	- 1 230	- 137.5	- 860
- 8.3	- 685	- 137.5	- 1 390	- 510	- 1 525			- 245	- 1 040
- 21.0	- 925	- 250	- 1 480	- 515	- 1 525			- 495	- 1 155
- 52.8	- 1 190	- 485	- 1 580					- 505	- 1 155
- 135.5	- 1 400	- 505	- 1 590						
- 258	- 1 490								
- 505	- 1 560								
<i>I<sub>r</sub></i>	625	770		835		605		670	
<i>H<sub>c</sub></i>	3.2	7.4		19.3		52		58	
<i>W</i>	28 000	68 000		108 000		170 000		217 000	
<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
46 <sub>q</sub>		50 <sub>q</sub>		70 <sub>q</sub>		101 <sub>q</sub>			
495	1 175	535	1 200	460	1 390	455	990		
253	1 075	270	1 080	270	1 325	242.5	930		
165	1 010	161.5	1 015	260	1 320	137.5	860		
+ 78.2	875	+ 78.5	890	140	1 245	+ 78.5	805		
0	640	0	645	134.5	1 230	0	640		
- 16.0	530	- 14.5	555	80.8	1 140	- 29.6	490		
- 32.8	292	- 21.9	500	+ 59.2	1 095	- 39.0	353		
- 44.0	102	- 33.3	347	0	860	- 42.8	290		
- 46.4	64.7	- 51.7	+ 20	- 16.2	705	- 47.1	199		
- 48.7	+ 14.0	- 58.7	- 128	- 27.3	+ 395	- 49.0	153.5		
- 52	- 43.7	- 79.2	- 550	- 34.1	- 139.3	- 53.5	+ 10.5		
- 60.6	- 262	- 124	- 865	- 43.5	- 700	- 58.6	- 153.5		
- 78.5	- 570	- 199	- 1 025	- 52.5	- 870	- 78	- 525		
- 139	- 915	- 291	- 1 090	- 99.5	- 1 130	- 121	- 750		
- 255	- 1 075	- 515	- 1 200	- 159	- 1 240	- 240	- 905		
- 495	- 1 175	- 535	- 1 200	- 264	- 1 330	- 450	- 980		
				- 515	- 1 390	- 455	- 990		
				- 460	- 1 390				
<i>I<sub>r</sub></i>	640	645		860		640			
<i>H<sub>c</sub></i>	50	53		33		54			
<i>W</i>	165 000	182 000		142 000		177 000			
<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
136 <sub>q</sub>		143 <sub>q</sub>		143 <sub>q</sub> †		143 <sub>q</sub> †		84 <sub>q</sub> (3 <sup>3</sup> )	
510	1 240	515	1 240	495	1 515	495	1 230	19	281
269	1 115	270	1 160	280	1 420	257	1 160	30	805
157.5	1 060	166.5	1 120	164	1 350	+ 168	1 110	78	1 227
+ 53.8	930	153.5	1 115	+ 52.1	1 180	0	850	247	1 372
0	800	105	1 060	0	900	- 39 0	670	377	1 410
- 26.9	685	98	1 055	- 16.2	630	- 58.5	450	675	1 450
- 53.8	480	55	985	- 21.6	350	- 60.5	410	776	1 465
- 59.3	+ 352	33.3	940	- 25.8	+ 5.8	- 67.2	+ 136.5	960	1 479



TABLE 12.—(Continued)

<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
136 <sub>q</sub>		143 <sub>q</sub>		143 <sub>q</sub> †		143 <sub>q</sub> ‡		84 <sub>q</sub> (33)	
-70.1	-28.6	+23.9	920	-26.9	-122.5	-72.3	-161	1 322	1 499
-78.2	-358	0	850	-31.7	-630	-96.5	-840		
-89.0	-635	-25.0	705	-55.0	-1 050	-136.5	-970		
-113.0	-855	-44.6	545	-113	-1 255	-257	-1 125		
-161.5	-995	-56.6	415	-290	-1 425	-495	-1 230		
-291	-1 115	-72.7	+23.7	-490	-1 510				
-490	-1 240	-74.2	-89	-495	-1 515				
-510	-1 240	-81.0	-323						
		-89.0	-624						
		-113.3	-880						
		-161.5	-1 050						
		-183	-1 085						
		-269	-1 140						
		-505	-1 240						
		-515	-1 240						
<i>I<sub>r</sub></i>	800	850		900		850		See below	
<i>H<sub>c</sub></i>	69	73		26		70			
<i>W</i>	260 000	280 000		115 000		265 000			

84<sub>q</sub>, *t<sub>q</sub>* = 950°C; see also Fig. 20

Bars§ (33)		Isthmus method (64)							
<i>H</i>	<i>I<sub>n</sub></i>	<i>H<sub>max</sub></i>	<i>B<sub>max</sub></i>	<i>B<sub>r</sub></i>	<i>H<sub>c</sub></i>	<i>H<sub>max</sub></i>	<i>B<sub>max</sub></i>	<i>B<sub>r</sub></i>	<i>H<sub>c</sub></i>
53	54	26	210	0		665	13 780	8 360	194
91	107	48	450	80	5.5	850	14 710	8 650	201
200	365	84			9	1 060	15 530	8 800	205
295	909	100	1 140	200		1 380	15 510	8 780	210
344	998	149	2 280	580	16	1 675	17 190	8 850	210
581	1 171	224	4 660	2 100	48	1 975	17 750	8 840	211
870	1 266	296	9 080	5 610	116	2 260	18 370	8 900	212
982	1 293	410	11 340	7 200	160	2 500	18 720	8 900	215
1 281	1 346	490	12 290	7 800	178				

\* Quenched at 800°C, excepting 26 at 1000°C, 33 at 850°C, and as noted.

† Not quenched.

‡ Section = 0.25 cm<sup>2</sup>.§ Normal magnetization; *H* = effective field intensity, corrected for demagnetizing field; bars, length = 20 cm; diameter = 0.5 cm.

TABLE 13.—COERCIVE FORCE AND RESIDUAL MAGNETIZATION AND THEIR VARIATION WITH HEAT TREATMENT

See also Table 12; for composition, see Table 1; temperatures are °C

Cobalt steels (25); see also Figs. 20, 21, 22

Key	% C	% Mn	% Co	Key	% C	% Mn	% Co	Key	% C	% Mn	% Co	% Cr
87	0.83	4.8	35	80	1.37	4.7	10	81	1.22	3.9	10	5.4
88	1.12	4.7	35	83	1.16	4.4	22	82	1.11	3.5	20	5.1
89	1.24	4.0	35	85	1.15	4.4	33	90	1.11	3.5	36	4.8
84	K. S. magnet steel 0.4 to 0.8% C, 30 to 40% Co, 1.5 to 3% Cr, 5 to 9% W; Figs. 20, 22, Table 12											
Quenched		Water		Oil		Magnetically very hard						
Key	$H_c$	$B_r$		$H_c$	$B_r$	Key	$H_{max}$	$B_r$	$H_c$			
87	132	8270		158.0	9350	90	540	8820	217.2			
88	149.3	9260		156.0	9580	90	820	9210	226.0			
89	149.2	9710		132.3	9720	90	1110	9310	227.1			
$t_q$	825°			850°		875°		900°				
Key	$H_c$	$B_r$		$H_c$	$B_r$	$H_c$	$B_r$	$H_c$	$B_r$			
80	70.7	3800		71.8	2650	63.3	1890	61.8	76			
83	126.4	8300		130.8	2240	118.0	7860	110.5	797			
85	131.2	8390		164.0	310	160.4	8890	150.3	1224			
81	110.0	8790		114.9	7760	113.2	7650	112.0	754			
82	114.2	9850		155.0	9430	153.3	9270	158.8	1322			
90	94.2	9530		200.1	9140	203.8	9130	207.8	1672			



TABLE 13.—(Continued)  
Square Bars (15);  $l = 20$  cm, section  $1 \times 1$  cm

$t_d$	$\tau_d$	$t_q$	$H_c$	$I_r$	Key	$\tau_d$	$t_q$	$H_c$	$I_r$
42, Carbon steel, C = 0.84%									
Undrawn			51	422	136		850	66	510
100	3 hr		45	415	137		830	68	500
100	10		45	396	138		800	69	540
100	16		44	397	139		850	51	460
100	24		44	390	140		850	74	530
150*	8.5		37	363	141		830	65	550
250†	7.5		28	310	142		1000	50	320
Total loss at 100°			13%	8%	143, W = 5.5%, C = 0.59%				
Total loss at 200°			41%	27%	$t_d$	$\tau_d$	$t_q$	$H_c$	$I_r$
91, Mo = 3.5%, C = 0.51%									
		850°	60	530	Undrawn			69	574
92, 93, Mo = 3.4 to 4.0%, C = 1.24 to 1.25%									
Undrawn			82.5	496	100	3 hr		65	583
60	7 hr		79.7	494	100	10		63	549
60	42		79.8	490	100	16		62	544
		800	82	480	100	24		61	540
		800	85	530	150*	8.5		46	465
94, Mo = 3.9%, C = 1.72									
Undrawn			79	429	250†	7.5		37	401
100	3 hr		73	433	Total loss at 100°			12%	6%
100	10		71	418	Total loss at 200°			17%	33%
100	16		70	416	Undrawn			70.7	561
100	24		70	413	60	7 hr		69.7	572
150*	8.5		50	417	60	42		69.9	564
250†	7.5		40	382	Undrawn			70.7	579
Total loss at 100°			12%	4%	60	52 hr		69.6	579
Total loss at 200°			50%	11%			770	72	560
		770	73	510	Quenched in H <sub>2</sub> O†			74	560
		830	79	415	Quenched in Hg			73	550
		800	78	560				78	540
144, W = 7.7%, C = 1.96%									
Undrawn					Undrawn			79.8	336
60	7 hr				60	7 hr		78.3	340
60	42				60	42		79.0	339
Unquenched								45	350
		800						85	370

\* In addition to 24 hr at 100°C. † In addition to 24 hr at 100°C and 8.5 hr at 150°C. ‡ 740° <  $t_q$  < 825°C; within this range, actual temperature is unimportant.

TABLE 14.—EFFECT OF MECHANICAL SHOCK (15)

Square bars 20 cm long, side of section =  $S$  mm; undrawn; dropped on pavement of hard sandstone, alternately with bar vertical, fall = 85 cm, and bar horizontal, fall = 30 cm. Initial magnetization (before being dropped) =  $I_r(\text{max.})$ . After being dropped  $N$  times, additional dropping produced no further change in  $I$ ; if  $I_e$  is this equilibrium value,  $I_r(\text{max.}) - I_e = \Delta \times I_r(\text{max.})$ . Drawing at 100 or at 200°C produces little change in  $\Delta$  and  $N$ ; for composition, see Table 1.

Key	$S$	$H_c$	$I_r(\text{max.})$	$\Delta$	$N$
26	10	3	27	>83%	>75
33	10	11	117	>45	>95
39	10	23	210	23	30
42	10	54	398	3.2	15
46	10	54	386	3.4	20
50	10	58	451	4.8	20
53	8.5	59	358	3.5	15
54	8.5	60	366	5.5	20
58	8.5	46	274	8.5	20
84*			854	6.3	850*
92	10	85	520	3.2	10
94	10	73	448	2.9	10
140	10	74	580	3.0	20

TABLE 14.—(Continued)

Key	$S$	$H_c$	$I_r(\text{max.})$	$\Delta$	$N$
143	10	72	570	6.0	45
143	10	73	560	5.0	50
143	8.5	94	680	2.6	10
144	10	86	390	1.5	5

\* Falls on concrete; equilibrium not attained for  $N = 200$ ; see Fig. 23.

TABLE 15.—EFFECT OF EXTERNAL MAGNETIC FIELD (15)

Bars are initially magnetized to  $I_r(\text{max.})$ ;  $H$  = field required to reduce magnetization to  $I = 0.90 I_r(\text{max.})$ ; for composition, see Table 1.

Key	39	93*	143*	143†	144*
$H_c$	21	80	70	71	78
$H$	3.5	21.0	13.5	13.0	27.5

\* Drawn at 60°C. † Undrawn.

TABLE 16.—TEMPERATURE COEFFICIENT

Bars 20 cm long, square section, side = 1 cm,  $I = 0.90 I_r(\text{max.})$ , centigrade temperature; for composition see Table 1

84	K. S. steel (33), $dI/dt = 0.00021I$ , $28^\circ\text{C} < t < 100^\circ\text{C}$
91 to 94	Molybdenum steel (15), $dI/dt = 0.0003I$
143	Tungsten steel (15) $dI/dt = 0.0002I$



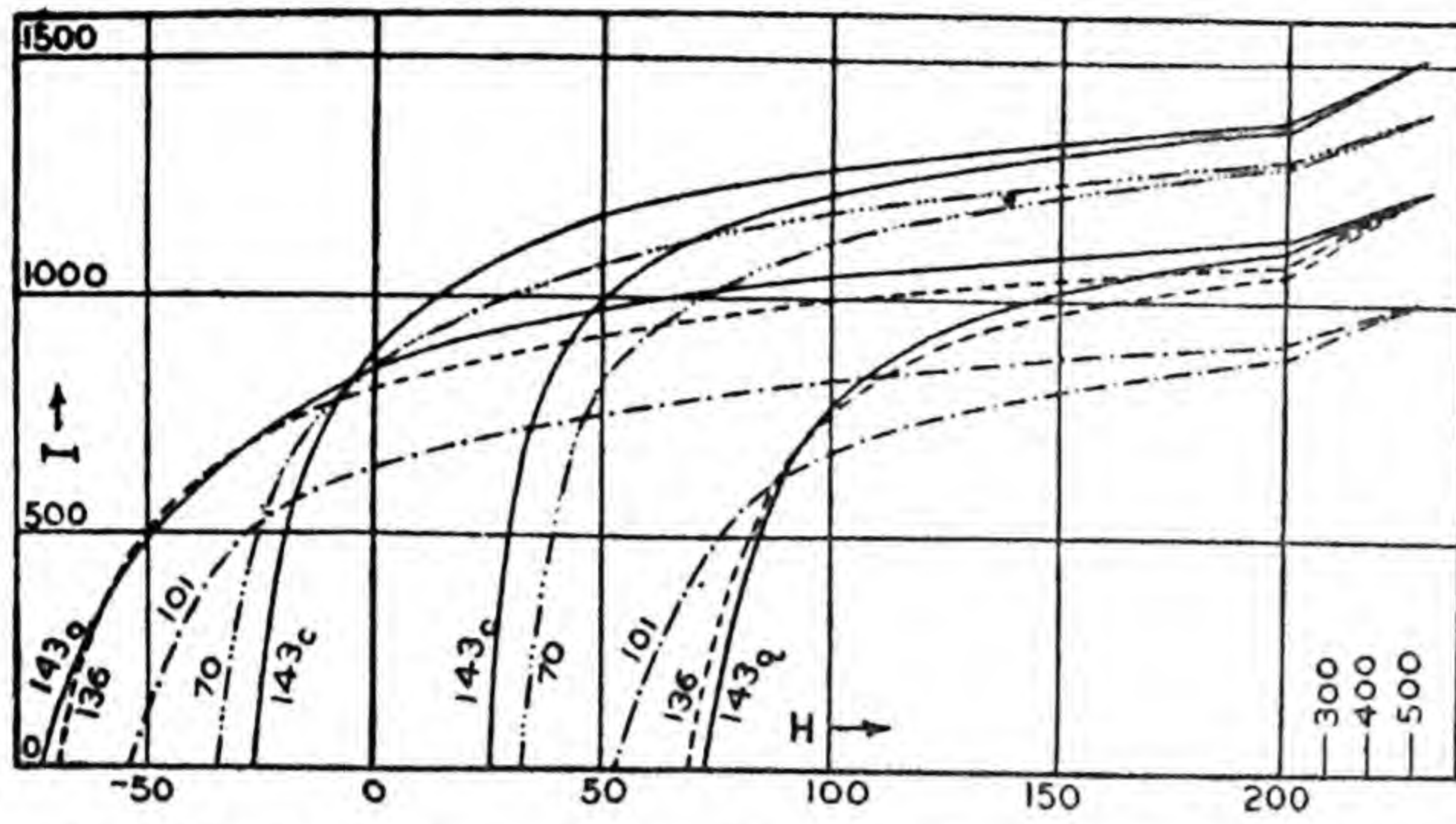


FIG. 18.—Carbon magnet steels. Cyclic magnetization (<sup>15</sup>). Data are from Table 12; on the curves are the key numbers (Table 1).

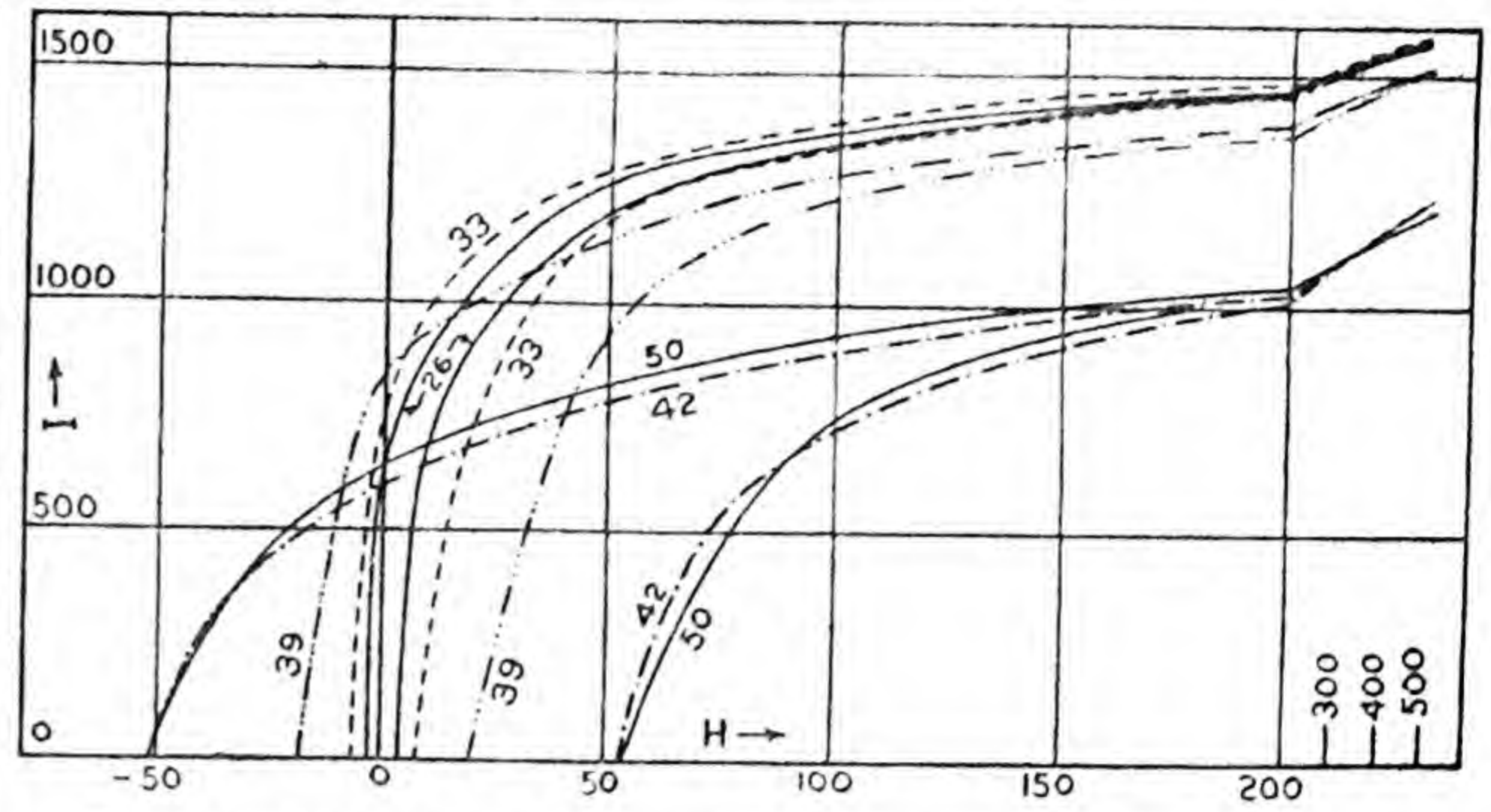


FIG. 19.—Special magnet steels: Cyclic magnetization (<sup>15</sup>). Data are from Table 12; on the curves are the key numbers (Table 1).

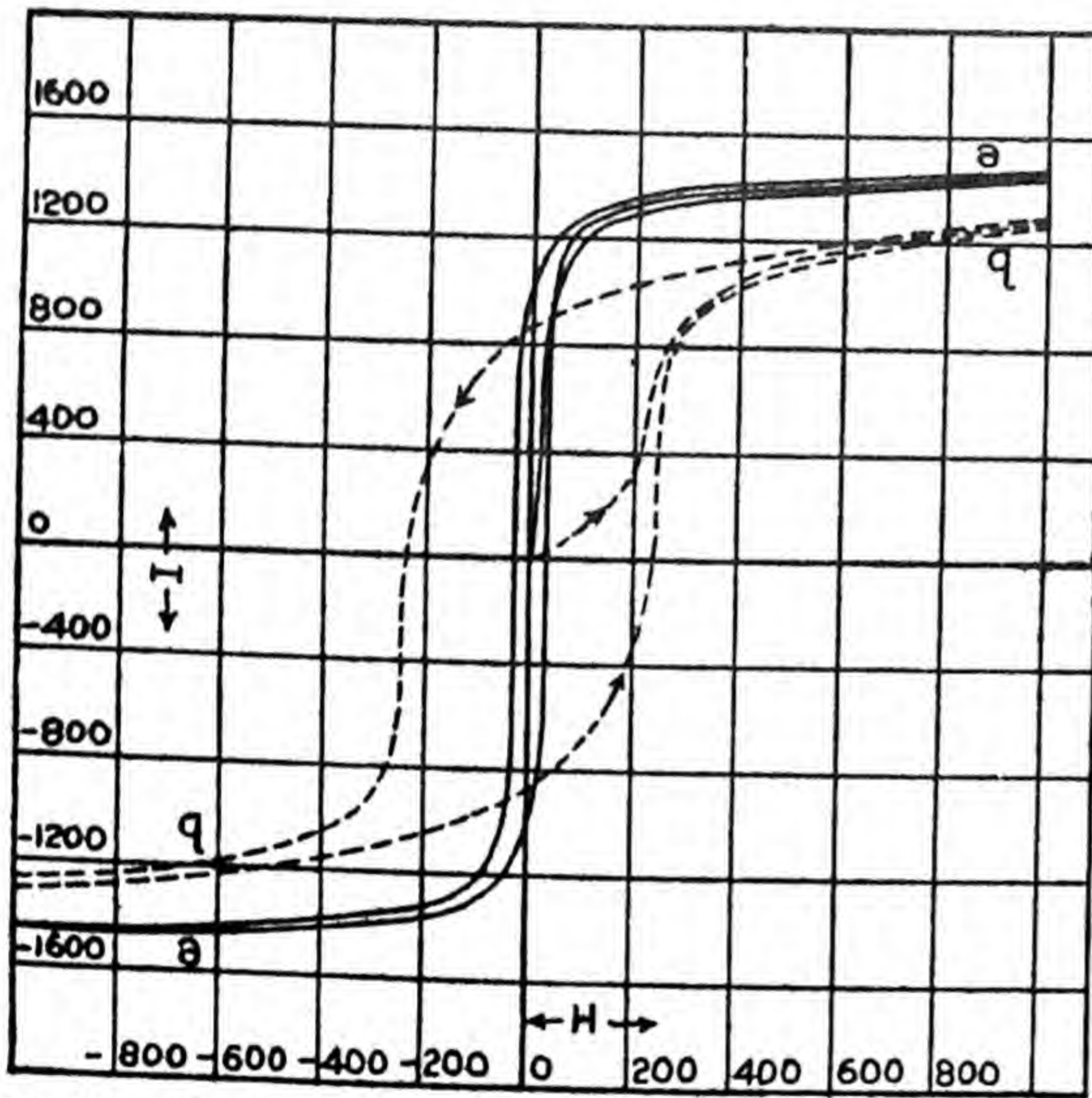


FIG. 20.—K. S. magnet steel: Cyclic magnetization (<sup>22</sup>). Key number 84 (Table 1); a = annealed, q = quenched at 950°C, cf. Table 12.

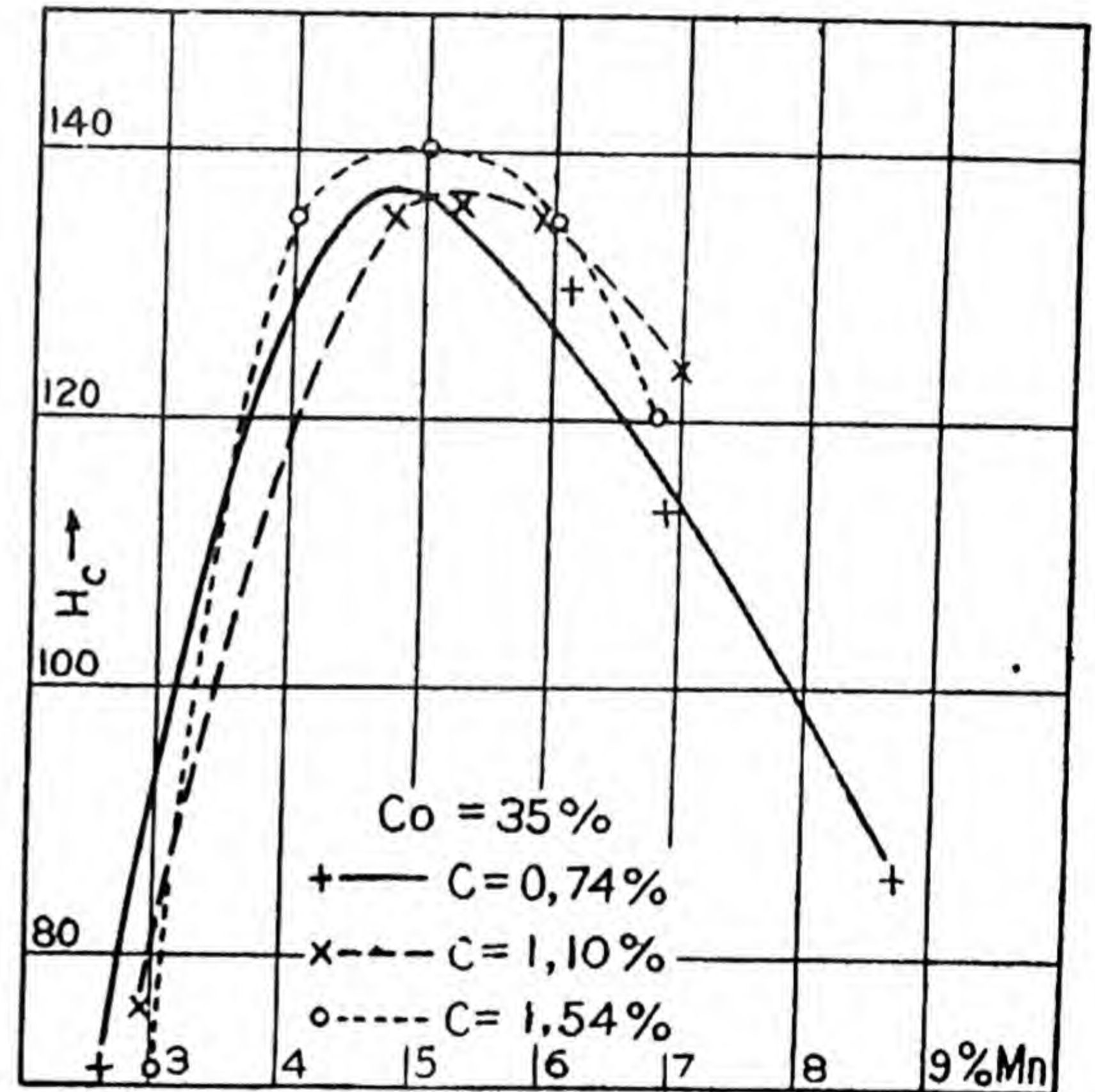


FIG. 21.—Cobalt steels: Effect of Mn upon coercive force (<sup>25</sup>).

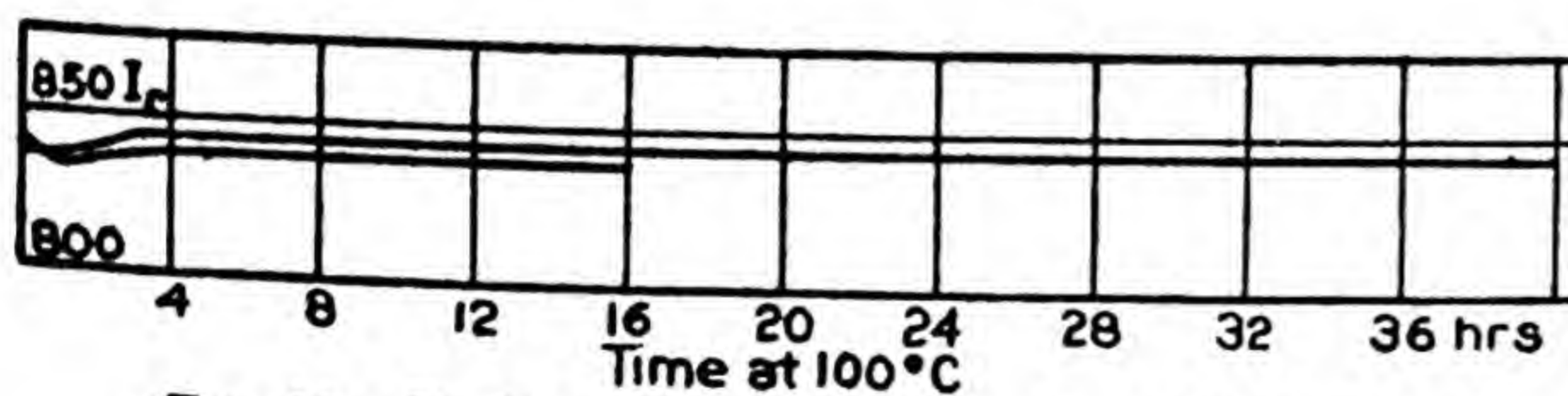


FIG. 22.—K. S. magnet steel: Aging at 100°C (<sup>22</sup>). Two specimens; key number 84 (Table 1).

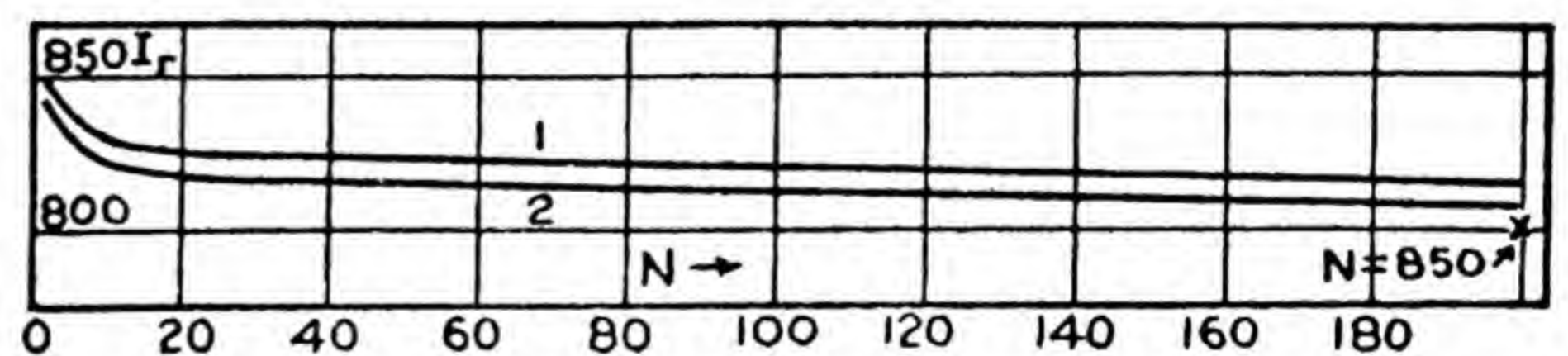


FIG. 23.—K. S. magnet steel: Effect of mechanical shock (<sup>22</sup>). Key number 84 (Table 1). N = number of falls; height of fall = 100 cm; strikes on (1) wooden floor, (2) concrete floor.



## Alloys of Iron

TABLE 17.—MAGNETIC PROPERTIES

For significance of key numbers, see Table 1; for carbon irons, see Tables 2 to 16

Al, Aluminium irons (23). Dissolved C increases  $H_c$ ; the addition of Al tends to counteract this effect. Material annealed in *vacuo* and cooled slowly, except as otherwise indicated;  $d_{red.} = 7.865 - 0.117p$ ,  $p < 54$ ;  $\rho = 9.9 + 11p$ ,  $p < 4$ ;  $\rho = 100$  approximately, if  $p = 10$ ;  $4\pi I_{red.} = 21\,640 - 570p$ ,  $p < 10$ ;  $1\,000\alpha = 0.35$  if  $p = 10$ .

Admixture			Admixture			$H_c$		
% C	Dissolved	Cementite	% C	% Al	Before annealed	Annealed 1100°	Quenched	
0.12	20	1.60	0.12	0.52	1.20	1.04	11.7	
0.13	21	1.68	0.13	3.19	1.08	0.97	3.8	
0.15	23	1.83	0.15	5.66	1.77	1.60	2.6	
0.10	18	1.45	0.10	10.52	0.90	0.84	1.3	
Key	77 <sub>a</sub> *	77 <sub>a</sub> †	78 <sub>a</sub> *	78 <sub>a</sub> †	79 <sub>a</sub> *	79 <sub>a</sub> †	79 <sub>a</sub> ‡	79 <sub>a</sub> ‡‡
H	$\mu_n$ , Normal permeability							
0.25	1 600	1 600	680	1 280	800	240	800	720
0.5	1 800	2 500	760	1 800	860	260	840	840
0.7	2 270	3 600	830	2 270	1 130	320	930	1 010
1.0	2 450	5 000	930	2 860	1 230	360	1 000	1 200
1.5	2 600	5 600	1 070	3 580	1 270	410	1 010	1 290
2.5	2 480	4 420	1 260	3 150	1 140	620	910	1 240
5	1 870	2 600	1 180	2 090	880	1 160	720	960
10	1 240	1 380	890	1 270	640	950	530	680
20	710	730	590	690	435	580	365	445
50	315	310	275	300	240	270	210	229
100	169.7	164.2	152.2	160.0	138.8	146.2	129.3	131.0
150	118.5	114.8	106.2	111.1	98.9	101.8	93.1	92.8
300	63.3		58.3		50.7			
500	39.7		36.8		31.2			
1 000	20.8		19.07		16.16			
000	11.00		10.06		8.62			
3 000	7.68		7.05		6.10			
4 000	6.01		5.54		4.84			
4 500	5.47		5.02		4.42			
B, Cyclic induction								
150	17 770	17 220	15 930	16 670	14 830	15 270	13 960	13 920
100	17 000	16 460	15 230	16 000	13 910	14 690	12 970	13 110
50	15 880	15 580	13 950	15 080	11 970	13 570	10 620	11 530
25	14 940	15 020	12 920	14 400	9 730	12 440	8 220	9 740
10	13 430	14 520	10 490	13 170	6 780	10 980	5 700	7 350
5	11 250	14 150	8 620	11 870	5 170	10 000	4 300	5 670
2.5	9 070	13 630	7 170	10 300	3 960	9 230	3 260	4 320
+ 1	7 050	12 920	5 900	8 700	2 020	8 560	2 430	3 370
0	4 900	11 700	4 700	6 900	2 150	7 940	1 680	2 350
- 0.5	2 920	10 270	3 870	5 300	1 360	7 580	1 020	1 500
- 0.75	+ 1 350	+ 6 800	3 360	3 720	800	7 350	+ 600	830
- 1.0	- 1 100	- 800	2 820	+ 950	+ 100	7 120	- 30	+ 60
- 1.5	- 3 300	- 7 050	+ 1 520	- 2 350	- 1 020	6 530	- 880	- 1 230
- 2.5	- 5 870	- 10 720	- 1 520	- 5 950	- 2 520	+ 4 760	- 1 960	- 2 730
- 5	- 9 100	- 12 800	- 5 470	- 9 530	- 4 300	- 3 360	- 3 440	- 4 670
- 10	- 12 200	- 13 570	- 8 840	- 12 200	- 6 300	- 9 230	- 5 170	- 6 730
- 20	- 14 250	- 14 400	- 11 700	- 13 700	- 8 700	- 11 470	- 7 280	- 8 880
- 50	- 15 680	- 15 500	- 13 830	- 14 970	- 11 900	- 13 440	- 10 500	- 11 450
- 100	- 16 970	- 16 420	- 15 220	- 16 000	- 13 880	- 14 620	- 12 930	- 13 100
- 150	- 17 770	- 17 220	- 15 930	- 16 670	- 14 830	- 15 270	- 13 960	- 13 920
$B_r$	4 900	11 700	4 700	6 900	2 150	7 940	1 680	2 350
$H_c$	0.91	0.96	1.99	1.08	1.10	4.19	0.84	0.90
$\mu_n(\text{max.})$	2 610	5 600	1 260	3 580	1 430	1 160	1 010	1 300
$\mu_0$	213		196		234			
$4\pi I_{\text{obs.}}$	20 100		18 150		15 540			
$4\pi I_{\text{red.}}$	20 340		18 460		15 750			
$1000\eta_{\text{max.}}$	1.30	1.52	1.98	1.50	0.87	3.44		
$\rho_{20}$	35.43		64.33		98.03			
$1000\alpha_{\text{red}}$	1.52		0.67		0.32			
$d_{\text{red.}}$	7.623		7.208		6.860			

\* Rod, annealed from 800°C.  
† Sheet, 0.5 mm, annealed from 800°C.  
‡ Annealed from 1100°C.



**B, Boron iron (91).** Addition of a small amount of B improves the iron by reducing FeO; a larger amount has an unfavorable effect; B is added as a flux in the form of B<sub>2</sub>O<sub>3</sub> containing 20.3% B; see Fig. 24.

**Co, Ferrocobalts.** Fe<sub>2</sub>Co is more magnetic than Fe (see Table 4); see also following table and Figs. 25, 26, p. 385 and Table 13 (80 to 90).

**79a** In an electric resistance furnace and a magnesia crucible, electrolytic Fe and pure Co from Merck were fused in hydrogen;  $I$  was measured from  $-188$  to  $1400^{\circ}\text{C}$ ,  $8\,800 < H < 13\,500$  gauss; by extrapolation of  $(\sigma^2, H^{-1})$  curve obtained  $\sigma_{\infty}$ ;  $\sigma$  corrected for expansion (53).

Co, %	$d_{20}$	$\sigma_{\infty}^*$	$\theta, ^{\circ}\text{C}$	Co, %	$d_{20}$	$\sigma_{\infty}^*$	$\theta, ^{\circ}\text{C}$
0	7.854	221	774	59.8	8.29	211	989
9.72	7.66	212	873	69.0	8.41	203	990
19.2	7.93	222	945	79.1	8.55	191	957
28.2	8.01	233	986	89.3	8.70	179	1037
38.1	8.09	233	995	100	8.87	168	1140
48.2	8.17	224	997				

\* For  $H = \infty$ ,  $t = -188^{\circ}\text{C}$  (53).

8611, Ferrocobalt, 34% Co; essentially Fe<sub>2</sub>Co (23)

Normal permeability				Cyclic induction			
$H$	$\mu_n$	$H$	$\mu_n$	$H$	$B$	$H$	$B$
2.5	1 580	150	149.7	$\pm 150$	$\pm 22\,450$	$-1.5$	$+5\,730$
5	1 530	300	79.0	$+100$	$+21\,220$	$-2.5$	$+1\,650$
7.5	1 320	500	48.2	50	18 640	$-5$	$-7\,000$
10	1 147	1 000	24.6	25	16 220	$-10$	$-11\,470$
20	724	2 000	12.8	5	11 800	$-20$	$-14\,480$
50	366	3 000	8.88	0	8 230	$-50$	$-18\,300$
75	266.1	4 000	6.92	$-0.5$	7 600	$-75$	$-19\,960$
100	211.0			$-1.0$	6 800	$-100$	$-21\,100$
$\mu_n(\text{max.})$	1 650	$4\pi I_{\infty}$	23 680	$B_r$	8 230	$H_c$	2.72
$\rho_{20}$	11.48	$1\,000\alpha$	2.2				

**Cr, Chrome irons (45);** material from Armstrong, Whitworth and Co.

Normal intensity of magnetization ( $I_n$ )

Annealed from 900°C*						Quenched at 900°C*						
$\frac{H}{\% \text{ Cr}}$	10	40	60	100	150	10	40	60	100	150		
1	460	844	940	1040	1117	60	588	796	960	1076		
	480	878	978	1082	1159	40	504	762	944	1060		
4.05	160	892	980	1078	1142	38	317	630	840	945		
	125	878	970	1088	1158	24	270	590	820	935		
8	88	790	888	984	1060	18	130	304	600	744		
	78	778	878	980	1070	17	120	286	580	724		
12	80	765	850	936	1008	20	112	235	485	653		
	70	750	840	932	1018	13	100	210	470	638		
16	70	635	710	780	850	17	84	162	360	508		
	55	608	695	784	865	12	76	145	340	492		
20	122	636	700	774	820	12	50	110	276	404		
	106	625	698	782	832	12	42	98	258	390		
$I_r$ , Residual magnetization†						$H_c$ , Coercive force						
% Cr =	1	4.05	8	12	16	20	1	4.05	8	12	16	20
A†	400	500	660	510	490	440	5	21	20	19	17	15
Q†	660	600	580	435	340	320	28	39	46	54	56	44

\* For each % Cr, the first line refers to  $15^{\circ}\text{C}$ , the second line to  $-190^{\circ}\text{C}$ .

† For cyclic magnetization,  $H_{\text{max.}} = 150$  gauss, room temperature.

‡ A = annealed from  $900^{\circ}\text{C}$ ; Q = quenched at  $900^{\circ}\text{C}$ .

**Cu, Iron-copper alloys.** Alloy A (9): Electrolytic Fe and Cu were fused in magnesia crucible; annealed at  $675^{\circ}\text{C}$ ;  $B_n$  is smaller if alloy is annealed at  $1000^{\circ}\text{C}$  or quenched at  $900^{\circ}\text{C}$ . Alloy B (61): Electrolytic Cu was fused with iron containing C = 0.08, Si = 0.01, Mn = 0.06, P = 0.01, S = 0.01, Cu = 0.03%; porcelain crucible, atmosphere of N. The Curie temperature ( $\theta$ ) and the temperatures at which the  $\gamma - \beta$  and  $\delta - \gamma$  transformations occur (centigrade temperature) are shown in the table.

Alloy A (room temperature)					Alloy B			
$H =$	10	20	50	100	% Fe	Heating	Cooling	
% Cu	$B_n$ , Normal induction					$\theta$ , °C	$\gamma - \beta$ , °C	$\delta - \gamma$
0.00	10 000	15 900	17 700	18 800	3	760		
0.09	5 700	13 200	16 800	18 300	5	763		
0.20	5 700	13 200	16 800	18 300	10	759		



TABLE 17.—(Continued)

Alloy A (room temperature) —(Continued)					Alloy B.—(Continued)			
<i>H</i> =	10	20	50	100	% Fe	Heating	Cooling	
% Cu	<i>B<sub>n</sub></i> , Normal induction					θ, °C	γ - β, °C	δ - γ
0.42	10 900	14 900	17 100	18 500	20	763	795	
0.80	6 300	14 000	16 900	18 500	30	764	795	
1.01	6 300	13 200	16 500	18 000	40	764	798	
1.51	4 300	12 600	16 600	18 200	50	766	803	
2.00	5 000	12 600	16 400	18 200	60	766	804	
3.99	5 700	12 900	16 300	18 000	70	766	804	
5.07	4 300	12 300	16 100	17 600	96	763	810	1 462
6.16	4 300	12 000	15 500	17 400	98	763	826	1 439
7.05	3 000	10 400	15 400	17 200	99	764	844	1 432
94.34	0	0	200	50	100	773	875	1 420

**Mn**, Manganese irons (23). Properties are complex. Quenched alloys are more magnetic ( $\mu_n$  greater) than those cooled slowly; for the former  $H_c$  attains 60, for the latter 130 gauss. If  $12 < p < 14$ , the alloy is practically nonmagnetic at room temperatures until after it has been chilled in liquid air; it is then magnetic. If  $p > 14$ , the alloy is not magnetic at room temperatures even after chilling in liquid air. If  $p < 8$ ;  $d_{20} = 7.873 - 0.008p$ ; from  $p = 8$  to  $p = 10$ ,  $d$  increases abruptly by 1.6%; if  $p > 10$ ,  $d$  decreases less rapidly than is indicated by equation. If  $p < 4$ ,  $\rho = 10 + 5p$ ; for  $p = 5.74$ ,  $\rho = 36$ ; for  $p = 7.81$ ,  $\rho = 45$ ; if  $10 < p < 16$ ,  $\rho = 50.6 + 0.7(p - 10)$ . After quenching at 800°C,  $4\pi I_\infty = 21\,425 - 210p$ , if  $p < 7.8$ ; if  $7.8 < p < 15$ ,  $4\pi I_\infty = 19\,800 - 2\,830(p - 7.8)$ ; if  $p = 15$ ,  $4\pi I_\infty$  is practically zero; see also p. 385, Table 12, (70, 80 to 90), and Fig. 21.

Key	71 <sub>q</sub>	72 <sub>q</sub>	73 <sub>q</sub>	74 <sub>q</sub>	75 <sub>q</sub>	76 <sub>q</sub>	75 <sub>s</sub>	76 <sub>s</sub>	76 <sub>s</sub>
H	Quenched at 800°C						$t_s = 800^\circ\text{C}$	$t_q = 660^\circ\text{C}$	Precooled*
	$\mu_n$ , Normal permeability								
5	80	80	76	56	22	6.0	15	1.6†	2.0†
10	90	90	88	60	24	7.0	16.5	2.0†	3.0†
20	125	123	113	63.5	25	7.0	18	2.3†	5.5†
50	230.0	220.0	205.0	110.6	29.0	7.6	20.4	3.10†	10.8†
100	150.6	146.5	139.8	102.0	38.5	8.4	22.0	3.45†	15.1†
150	111.3	108.9	104.5	79.1	35.5	8.7	21.4	3.60	14.9
300	62.7	62.3	60.2	46.8	24.13	7.30	15.80	3.33	11.23
500		39.40	38.44	30.80	17.12	6.04	11.80		
1 000		20.94	20.48	16.88	10.14	4.27	7.37		
2 000		11.11	10.88	9.26	6.09	3.015	4.59		
3 000		7.760	7.603	6.590	4.533	2.477	3.527		
4 000		6.070	5.955	5.225	3.712	2.168	2.965		
5 000		5.054	4.964	4.396	3.210	1.966	2.612		
6 000		4.375	4.302	3.832	2.860	1.820			
6 500		4.112	4.048	3.616	2.725	1.759			
B, Cyclic induction									
300	18 880	18 680	18 050	14 030	7 240	2 200	4 740	1 000	3 370
200	17 810	17 540	16 900	13 000	6 650	1 840	4 230	800	2 950
150	16 970	16 600	15 940	12 300	6 220	1 600	3 880	680	2 680
100	15 720	15 220	14 530	11 380	5 690	1 320	3 490	545	2 350
50	13 640	13 100	12 500	10 130	5 070	1 030	3 000	400	1 960
25	12 100	11 500	10 870	9 200	4 660	840	2 720	325	1 720
10	10 900	10 260	9 560	8 500	4 400	750	2 550	270	1 550
+ 5	10 380	9 700	9 100	8 230	4 280	700	2 480	255	1 490
0	9 700	9 050	8 600	7 900	4 150	660	2 400	230	1 430
- 5	9 000	8 380	8 000	7 500	4 020	620	2 270	215	1 360
- 10	8 170	7 500	7 300	7 080	3 880	580	2 100	195	1 290
- 20	+ 5 750	+ 5 000	+ 5 100	6 100	3 550	475	1 740	150	1 140
- 30	- 2 500	- 3 550	- 1 400	+ 4 600	3 150	360	1 380	+ 100	960
- 50	- 11 360	- 11 000	- 10 250	- 3 000	+ 2 100	+ 80	+ 600	- 5	+ 450
- 75	- 13 850	- 13 400	- 12 600	- 8 340	- 1 500	- 380	- 540	- 160	- 600
- 100	- 15 060	- 14 650	- 13 980	- 10 200	- 3 670	- 720	- 1 770	- 305	- 1 380
- 150	- 16 700	- 16 340	- 15 680	- 11 860	- 5 330	- 1 260	- 3 150	- 540	- 2 240
- 200	- 17 680	- 17 430	- 16 800	- 12 880	- 6 200	- 1 660	- 3 900	- 710	- 2 720
- 300	- 18 880	- 18 680	- 18 050	- 14 030	- 7 240	- 2 200	- 4 740	- 1 000	- 3 370
B <sub>r</sub>	9 700	9 050	8 600	7 900	4 150	660	2 400	230	1 430
H <sub>c</sub>	24.0	23.0	24.9	39.4	58.5	53.6	65.2	48.0	60.7



TABLE 17.—(Continued)

Key	71 <sub>q</sub>	72 <sub>q</sub>	73 <sub>q</sub>	74 <sub>q</sub>	75 <sub>q</sub>	76 <sub>q</sub>	75 <sub>a</sub>	76 <sub>q</sub>	76 <sub>q</sub>
	Quenched at 800°C						<i>t<sub>a</sub></i> = 800°C	<i>t<sub>q</sub></i> = 660°C	Precooled*
$B_r H_c / 1000$	233	208	214	311	242	35	156	11	87
$\mu_n(\text{max.})$	235	226	205	116	40	9.0	22	3.6	15.2
$\mu_0 \ddagger$		73	63	32.5	10				
$4\pi I_{\text{cobs.}}$		20 280	19 850	17 110	11 360	5 200	8 500		
$4\pi I_{\text{red.}}$		20 570	20 270	17 750	11 700	5 350			
$\rho_{20}$	24.63	30.38	35.37	45.42	51.83	53.41	50.84		
$1000\alpha_{\text{red.}} \S$	3.03	2.67	2.38	2.06	2.00	1.86	2.00		
$d_{\text{red.}} \S$	7.8566	7.8550	7.8438	7.8451	7.9708	7.9826			

\* Precooled to  $-78^\circ\text{C}$ . † Deduced from hysteresis cycle. ‡ Before annealing. § After slow cooling.

Mo, Molybdenum steel. See Tables 13 to 16, 91 to 94.

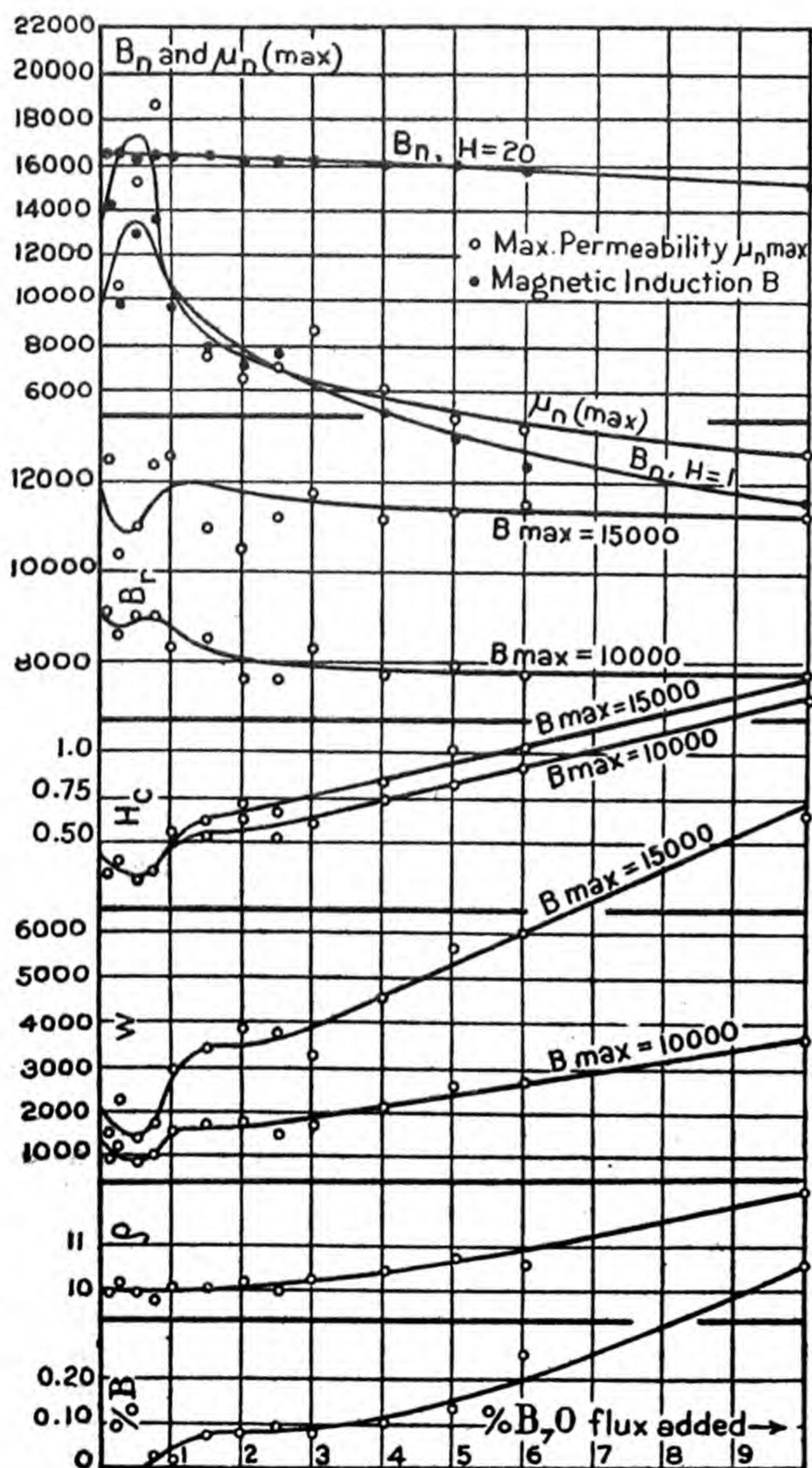


FIG. 24.—Iron-boron (Fe-B) alloys (51).

In lowest section, "% B" = actual % B as determined by chemical analysis of resulting alloy. Unit of  $\rho$  = 1 microhm-cm; of other quantities = 1 cgm unit.

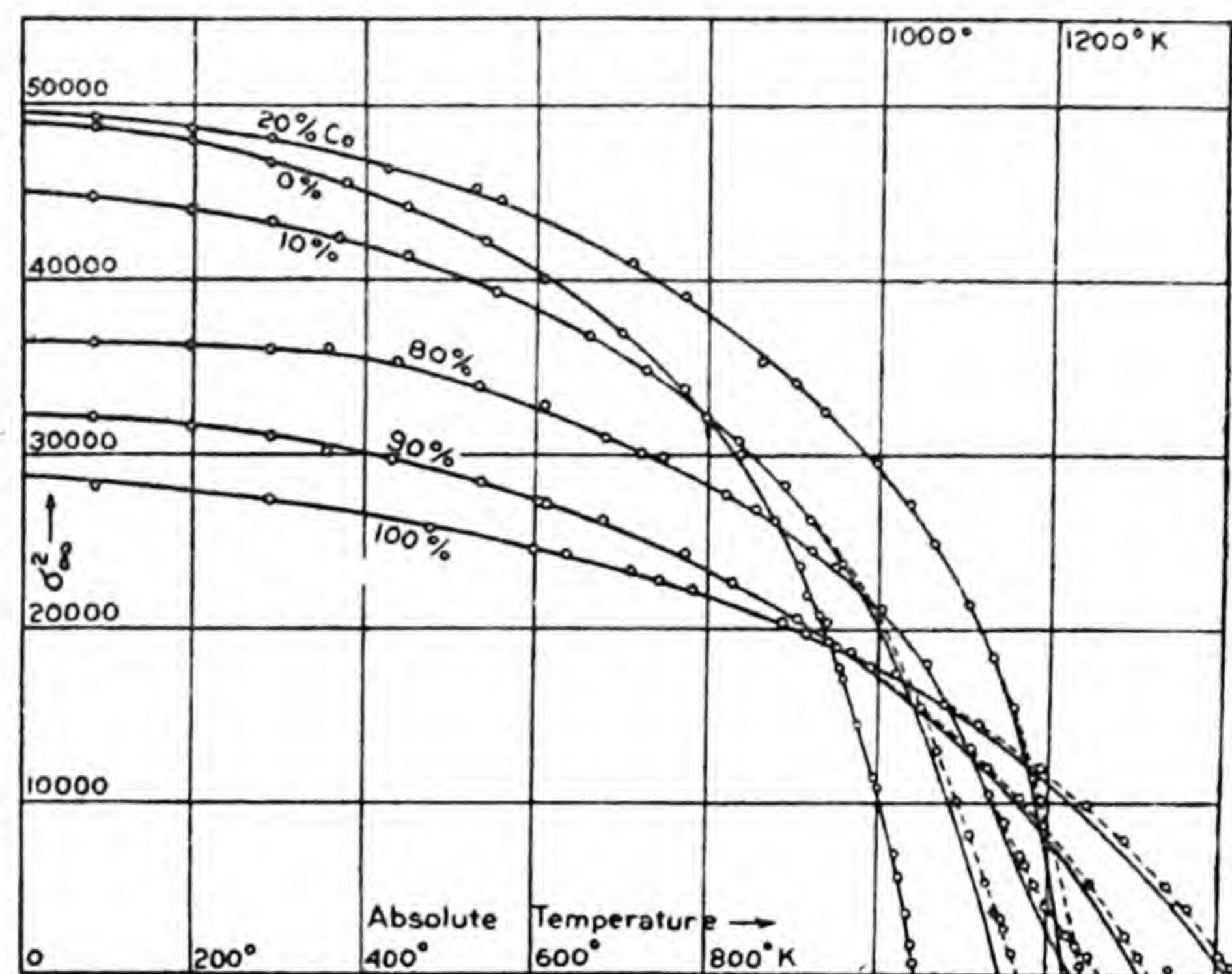


FIG. 25.—Ferrocobalts (Fe-Co): Variation of magnetization with absolute temperature (53); v. also Fig. 26.

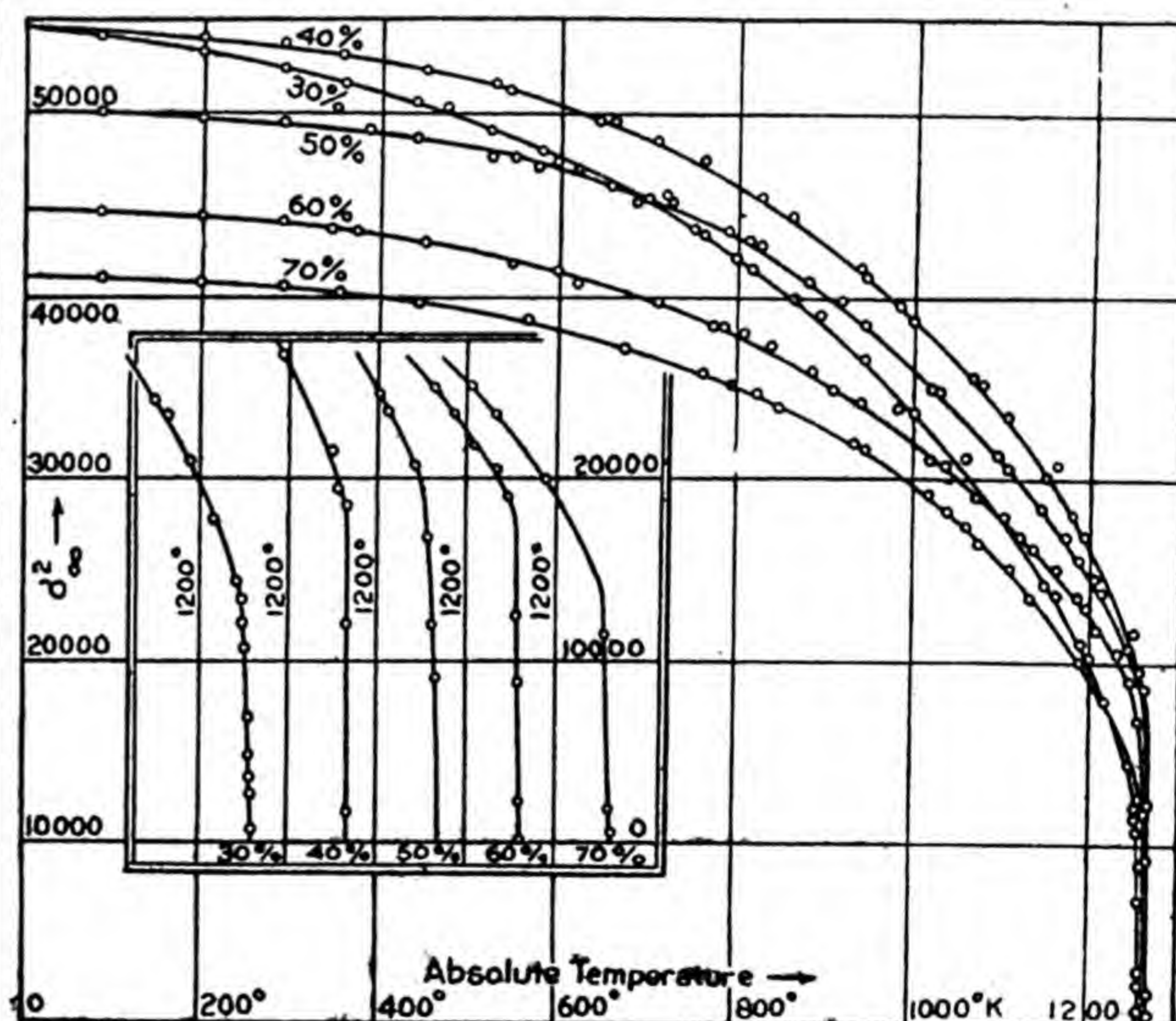


FIG. 26.—Ferrocobalts (Fe-Co): Variation of magnetization with absolute temperature (53); v. also Fig. 25.



**Ni, Ferronickels.** See also Table 12, 101. The initial permeability ( $H$  very small) of ferronickels containing from 30 to 90% Ni exceeds that of pure Fe; it has a very marked maximum near 78.5% Ni. See Fig. 27. For permalloy, see p. 396.

**95** In a high-frequency electric induction furnace, pure Ni and electrolytic Fe were fused *in vacuo*. The Ni was from Mond, and contained Ni, 99.89%; Cu, 0.004; Fe, 0.053; C, 0.045; S, tr.; SiO<sub>2</sub>, 0.008.  $\Theta_\beta$  = Curie point corresponding to transformation to state  $\beta$ ;  $\Theta_w$  is defined by  $\chi(T - \Theta_w) = \text{constant}$  (see Curie point, p. 369), the material being in the  $\gamma$ -state (face-centered cube); and  $\Theta_f$  = temperature of transformation ( $\alpha - \gamma$ ) as determined by ferromagnetic method (51).

Temperatures  $t$ ,  $\Theta$  are °C

$t$	+16°	-79°	-188°	-273°*	$\Theta_\beta$	$\Theta_w$	$\Theta_f$
% Ni	$\sigma_\infty$						
0	217.4	219.7	221.1	221.5	771	-5500	
1.4	217.6	220.0	221.4	221.9	766	-3380	
3.5	218.4	221.3	223.0	223.5			
5.05	218.5	221.3	223.5	224.0	752	-2870	
6.9	218.1	221.8	223.6	224.2			
11.3	216.2	220.0	222.3	223.0		-1240	
15.9	213.7	217.9	221.4	221.8		-646	
19.0	211.0	215.6	219.4	220.1		-252	
25.2	200.9	207.1	211.1	212.1		-12	
25.5	199.7	206.2	210.0	211.0			
29.7	185.3	191.3	197.0	198.7		+162	+120
31.3	179.6	186.9	192.4	194.1			
31.8	177.8	185.2	191.5	193.3		197	160
33.3	150.6	166.2	178.0	181.6			
33.8	148.1	164.2	176.7	180.2			
35.3	128.1	151.7	170.2	178.4		299	261
37.0	138.1	158.5	173.2	177.3		312	285
39.0	148.3	164.7	175.6	177.7		355	317
40.8	151.1	165.8	175.9	177.9		380	321
42.0	157.0	168.4	175.4	176.5		410	346
43.5	157.2	167.5	172.8	174.3		433	403
49.6	153.8	159.0	163.1	164.0		522	506
51.0	151.7	157.0	161.0	161.7			
57.7	141.8	145.3	147.8	149.0		600	590
67.0	127.5	129.9	131.9	132.3		622	612
80.2	99.7	101.3	102.1	102.4		599	576
87.7	82.9	84.3	85.0	85.4		539	511
100	55.1	56.8	58.1	58.4		382.0	360
100†	55.1	56.9	57.8	58.0			

\* Extrapolated. † Ni from Merck.

Electrolytic Fe and electrolytic Ni were fused in magnesia crucible, pressure = 1 to 2 mm of mercury. The Fe and Ni used contained the following impurities (tr. = trace only):

	C	S	Si	Mn	P	Cu	Al	Ni	Fe	
Fe.....	0.014	0.003	tr.	tr.	tr.	tr.	0.005		99.978	%
Ni.....	0.030	0.006	0.040	tr.	0.001			99.673	0.250	%

These alloys and others prepared from them by adding known amounts of one, or more, other elements (Al, Mn, Si, or Ti) were studied. All were annealed at 900 to 1000°C and cooled slowly (24 hr) (93). In the following tables, the Ni refers to this 99.673% material.

Key	96	99	102	104	106	109	112
Ni =	0.50	1.96	3.85	5.68	7.33	9.61	11.10%
$H$	$B_n$ , Normal induction						
0.2	600	200	100	200	100		
0.4	3 400	600	200	600	300		100
1.0	13 600	7 200	1 600	4 500	1 200	300	300
4.0	15 700	13 400	13 200	11 000	7 600	3 400	2 900
20.0	16 500	16 700	16 400	14 500	16 200	13 000	13 300
100.0	18 300	18 600	18 600	16 700	19 100	18 700	19 100
400.0	21 200	21 600	21 800	19 100	21 600	21 000	21 500
Annealed	920°	940°	902°	923°	1 064°	920°	923°C
$\mu_n(\text{max.})$	18 200	8 200	4 350	4 500	2 130	810	855
$B_\mu^*$	10 000	10 000	10 000	8 220	5 000	10 000	8 900
$W^\dagger$	1 175	1 900	3 300	2 440	4 225	9 270	9 450
$H_c^\dagger$	0.39	0.65	1.10	0.80	1.45	3.30	3.70



TABLE 17.—(Continued)

Key	115	117	123	125	127	128	129
Ni =	15.87	21.03	38.92	54.08	57.99	66.96	75.80 %
H	$B_n$ , Normal induction						
0.2			300	3 600	2 600	200	100
0.4			1 000	7 300	3 600	400	700
1.0	200	100	3 000	11 100	5 200	2 600	4 200
4.0	1 100	500	6 400	13 700	7 900	10 000	9 000
20.0	8 100	5 400	10 400	15 600	12 200	13 100	11 100
100.0	15 200	15 200	12 400	15 600	13 800	13 600	11 400
400.0	19 700	20 000	12 200	16 000	14 200	13 900	12 000
Annealed	923°	923°	923°	923°	923°	923°	931°C
$\mu_n(\text{max.})$	475	276	3 060	19 600	14 500	3 200	4 230
$B_\mu^*$	5 000	4 500	2 300	5 200	1 888	5 500	4 400
$W^\dagger$	13 080	30 000	1 030	580	194	1 330	627
$H_c^\dagger$	5.10	13.00	0.45	0.18	0.14	0.56	0.34
Alloys containing 0.2% Al				Alloys containing 0.2% Ti			
Key	118	120	121	110	114	116	119
Ni =	23.8	25.1	29.8 %	9.9	15.0	20.0	25.0 %
H	$B_n$ , Normal induction						
1.0	30	50	400	200	100	50	50
4	200	300	800	1 700	1 300	400	300
20	2 800	3 800	1 500	11 000	7 300	4 800	3 600
100	12 100	12 900	2 100	18 900	16 500	14 700	12 000
400	16 300	17 000	2 800	21 500†	20 500‡	19 400‡	15 900‡
Annealed	950°	950°	950°	920°	900°	917°	917°C
$\mu_n(\text{max.})$	200	172	400	605	405	240	187
$B_\mu^*$	5 000	8 600	400	10 000	4 050	6 000	6 000
$W^\dagger$	10 860	8 950	278	10 700	15 150	28 200	36 900
$H_c^\dagger$	12.80	10.20	0.50	4.10	5.70	12.00	15.00
Alloys containing 0.5% Mn						0.1% Mn + 0.2% Si	
Key	124§	126	132	133	134	107	111
Ni =	50.0	54.9	89.9	93.3	99.9 %	8.0	10.00 %
H	$B_n$ , Normal induction						
0.4	800	300	100	100		100	70
1.0	3 400	2 700	600	300		500	200
4.0	9 300	8 700	3 600	3 100	400	5 200	2 200
20.0	13 800	13 700	6 700	5 800	4 700	14 400	12 400
100.0	15 500	14 300	8 000	7 200	6 200	19 200	18 500
400.0	16 300	14 800	8 500	7 600	6 800	21 900	21 500
Annealed	931°	931°	931°	931°	931°	900°	900°C
$\mu_n(\text{max.})$	3 570	2 860	1 040	800	500	1 300	640
$B_\mu^*$	4 600	4 300	2 400	2 400	2 000	5 200	6 400
$W^\dagger$	2 315	1 177	1 453	2 055	3 640	5 990	11 200
$H_c^\dagger$	0.89	0.68	1.42	1.80	3.20	2.36	4.10
Alloys containing 0.2% Si							
Key	97	98	100	103	105	108	113
Ni =	0.50	1.00	1.96	3.85	7.00	9.52	15.0
H	$B_n$ , Normal induction						
0.2	200	150	150	100	200		100
0.4	1 400	500	400	300	500	100	200
1.0	10 800	7 600	4 200	2 000	1 300	300	400
4.0	15 300	15 200	14 700	13 600	8 100	2 700	1 400
20.0	16 400	16 600	16 600	16 900	16 000	10 600	7 500
100.0	18 200	18 400	18 500	18 600	19 200	17 000	16 500
400.0	21 100	21 400	21 500	21 500	22 000	19 900	20 900
Annealed	920°	900°	940°	902°	1 064°	920°	960°
$\mu_n(\text{max.})$	11 000	8 330	6 060	4 500	2 400	556	450
$B_\mu^*$	10 000	10 000	10 000	9 000	6 000	10 000	4 000
$W^\dagger$	1 570		2 420	3 030	3 760	10 150	12 300
$H_c^\dagger$	0.52		0.80	1.02	1.30	3.90	5.00

\*  $B_\mu$  = value of  $B_n$  for which  $\mu_n = \mu_n(\text{max.})$ . † Cyclic,  $B_{\text{max.}} = 10\ 000$ . ‡ For  $H = 300$ . § For  $H = 0.2$ ,  $B_n = 300$ . || For  $H = 0.2$ ,  $B_n = 100$ .



**130 Permalloy.** Typical composition: 78.3% Ni, 21.35% Fe, 0.37% Co, 0.22% Mn, 0.10% Cu, 0.04% C, 0.035% S, 0.003% Si, traces of P. Heated 1 hr at 900°C and cooled slowly; reheated to 600°C and cooled on Cu plate at room temperature (4).  
For  $B_{max.} = 5\,000$ ,  $W$  and  $H_c$  are, each, only  $\frac{1}{16}$  of its value for soft Armco iron.  $\mu_n(max.) = 87\,000$  (Fig. 28) is not exceptional (4). Reluctivity (38) is  $\mu_n^{-1} = (a + bH)10^{-5}$ ; if  $0 < H < 0.04$ ,  $a = 9.5$ ,  $b = -225$ ;  $0.06 < H < 4$ ,  $a = 0.5$ ,  $b = +9.85$ ;  $4 < H < 22$ ,  $a = 0.3$ ,  $b = +9.1$ . For other data, see Figs. 28 to 33.  
**Sb, Antimony irons (71).** Alloys were prepared from Swedish iron and "pure antimony" of commerce, free from As and Pb. Bars were cast in iron molds.  $\kappa_0$  = initial susceptibility ( $H = 0$ );  $W$  = hysteresis loss per cycle,  $W = \eta B^e$ .

% Sb	$\kappa_0$	% Sb	$\kappa_0$	$\eta$	$e$	% Sb	$\kappa_0$	$\eta$	$e$
26.0	0.000091	38.6	0.0051			51.2	0.330	1.95	1.78
29.8	0.00023	42.7	0.125	1.39	2.17	54.4	0.82	1.06	1.78
33.9	0.00050	45.2	0.167	2.10	1.99	56.8	1.06	1.15	1.70

**Si, Silicon irons.** See also Tables 3, 4, 9, 11, 60 to 69, Table 7, Figs. 11, 13. The presence of Si in C-irons, with prolonged heating at 975°C, prevents  $H_c$  from rising above its value for nearly pure Fe. In ferrosilicons which are as pure and as poor in C as commercially obtainable,  $H_c$  for  $B_{max.} = 10\,000$  may be as low as 0.4 or 0.5 gauss (23). In certain cases  $\mu_n(max.)$  exceeds that for pure iron. For anhysteretic magnetization, see Table 2 (65).  
**Silicon steel (23).** If unannealed,  $d_{red.} = 7.874 - 0.0622p$ ,  $p < 4$ ;  $\rho_{20, red.} = 9.9 + 12p$ ,  $p < 4$ ; for  $p = 4.45, 5.26, 8.42$ ,  $\rho = 61.26, 71.86, 93.46$ , respectively.  $4\pi I_{\infty red.} = 21\,600 - 480p$ .

Si.....	0	0.075	0.315	0.63	1.03	2.41	3.70	4.45	5.26%
1000 $\alpha$ .....	5.7	5.4	4.2	3.2	2.5	1.3	0.87	0.68	0.52

Admixture		$H_c$		Admixture		$H_c$		
% C	Dissolved	Cementite	% C	% Si	Before annealed	Annealed 700°C	Annealed 975°C	
0.21	13	2.3	0.21	2.4	1.30	1.19	0.70	
0.29	18	2.9	0.29	4.5	1.26	0.65	0.69	
0.18	11	2.1	0.18	5.25	1.93	0.70	0.59	
0.34	20	3.2	0.34	8.35	6.56	4.60	0.70	

Key	60*	60†	61*	61†	63*	63†	67*	67†
$H$	$\mu_n$ , Normal permeability							
0.25	800	1 680	1 000	2 000	3 280	1 200	2 200	800
0.5	1 300	3 000	1 400	2 700	4 200	1 720	3 100	1 240
0.75	2 000	6 930	1 870	6 000	4 540	2 530	3 870	1 970
1.0	2 700	8 450	2 300	7 650	4 650	3 200	4 200	3 000
1.5	3 400	6 930	2 760	7 130	4 490	3 530	4 200	5 670
2.5	3 300	5 290	2 570	5 080	3 870	3 300	3 600	4 570
5	2 300	2 920	2 030	2 820	2 660	2 350	2 430	2 570
10	1 390	1 530	1 330	1 480	1 490	1 360	1 370	1 350
20	760	790	730	770	780	730	730	710
50	330	335	320	330	335	315	315	305
100	176	179	171	174	177	168	170	163
150	122	124	120	121	123	116	119	114
300	66		65		65		62	
500	42		40		40		38	
1 000	22		21		21		20	
2 000	11		11		11		11	
3 000	7.9		7.7		7.6		7.4	
4 000	6.212		6.052		5.94		5.778	
4 500	5.633		5.514		5.39		5.251	

$B$ , Cyclic induction								
150	18 400	18 600	17 950	18 200	18 400	17 500	17 900	17 070
100	17 560	17 900	17 150	17 430	17 670	16 800	17 000	16 310
50	16 580	16 970	16 100	16 500	16 680	15 780	16 830	15 330
25	15 820	16 300	15 260	15 830	16 010	15 030	14 980	14 710
10	15 100	15 810	13 870	15 320	15 260	14 200	14 260	14 100
5	14 370	15 500	11 620	15 000	14 360	13 220	13 500	13 820
2.5	13 300	15 300	9 900	14 710	12 800	11 350	11 840	13 600
+ 1	11 780	15 100	8 060	14 460	10 160	9 050	9 660	13 330
0	9 850	14 800	5 700	14 080	6 800	6 600	6 000	13 000
- 0.25	9 200	14 500	4 850	13 780	5 400	5 700	4 000	12 820
- 0.5	8 400	13 880	3 700	12 750	+ 3 300	4 300	+ 1 600	12 550
- 0.75	7 350	+ 4 800	+ 2 150	+ 7 700	- 1 500	+ 1 800	- 980	11 800



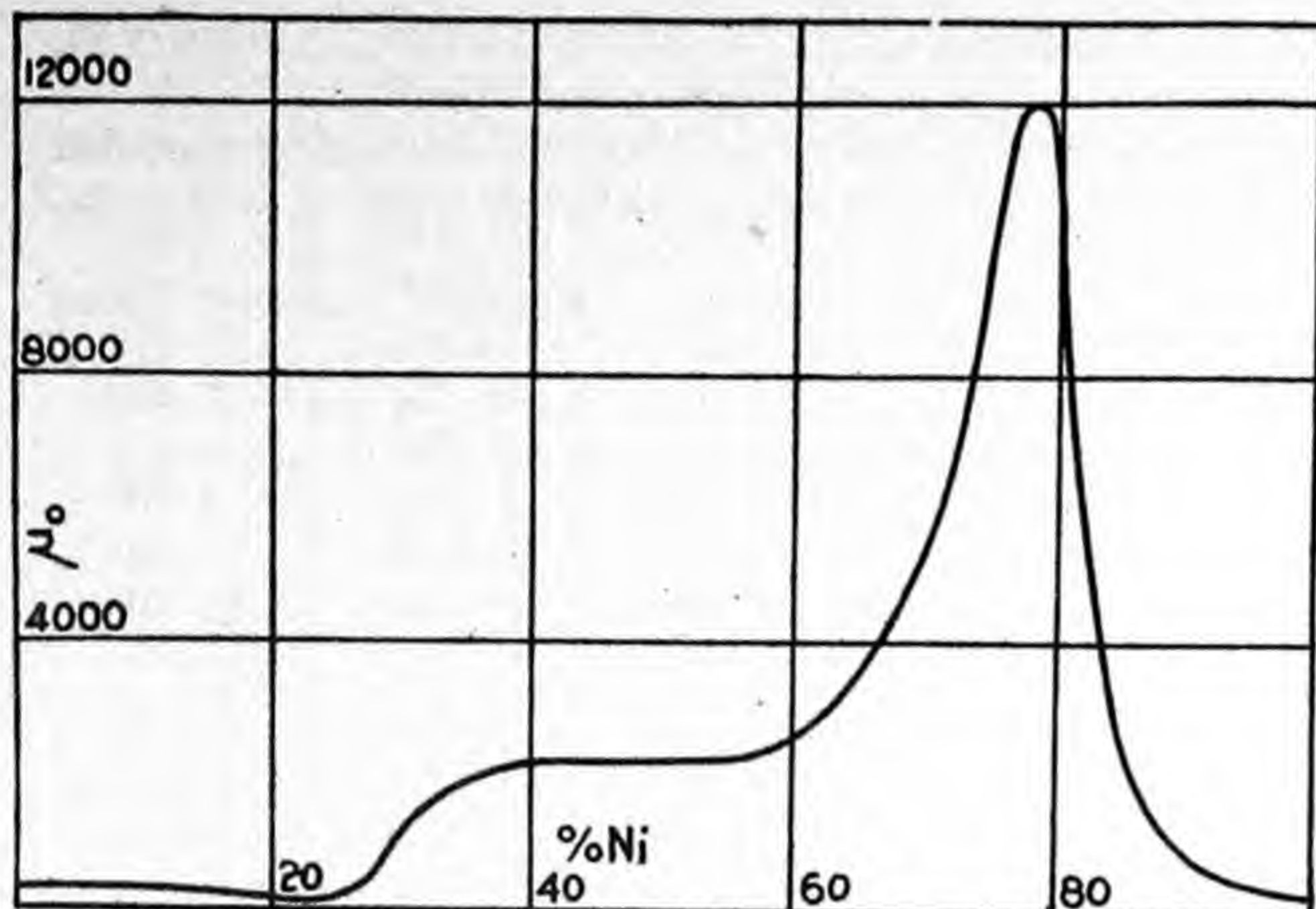
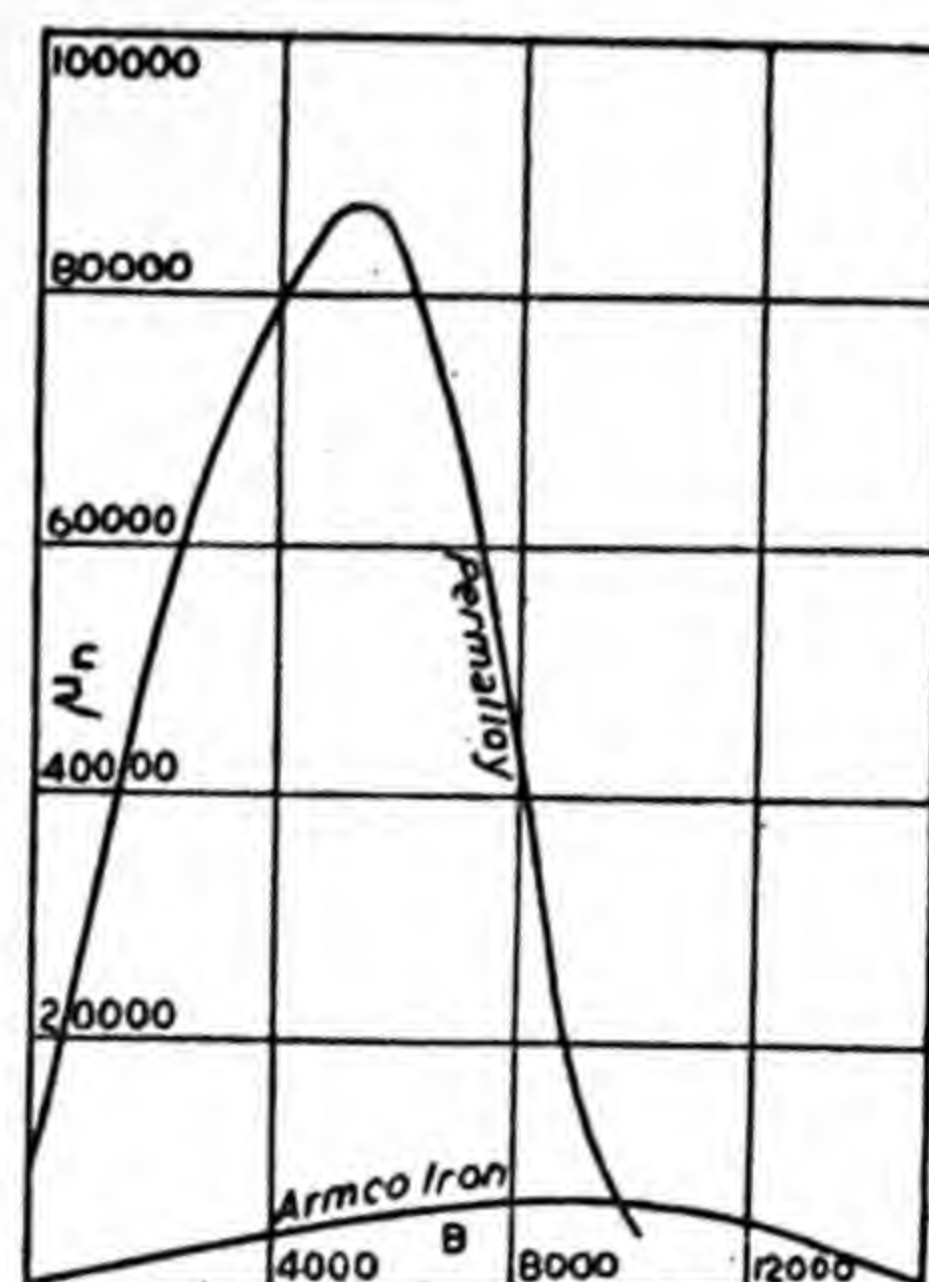

 FIG. 27.—Ferronickels (Fe-Ni): Variation of initial permeability ( $\mu_0$ ) with amount of Ni (4).


FIG. 28.—Permalloy (130): Normal permeability (4); cf. Fig. 29.

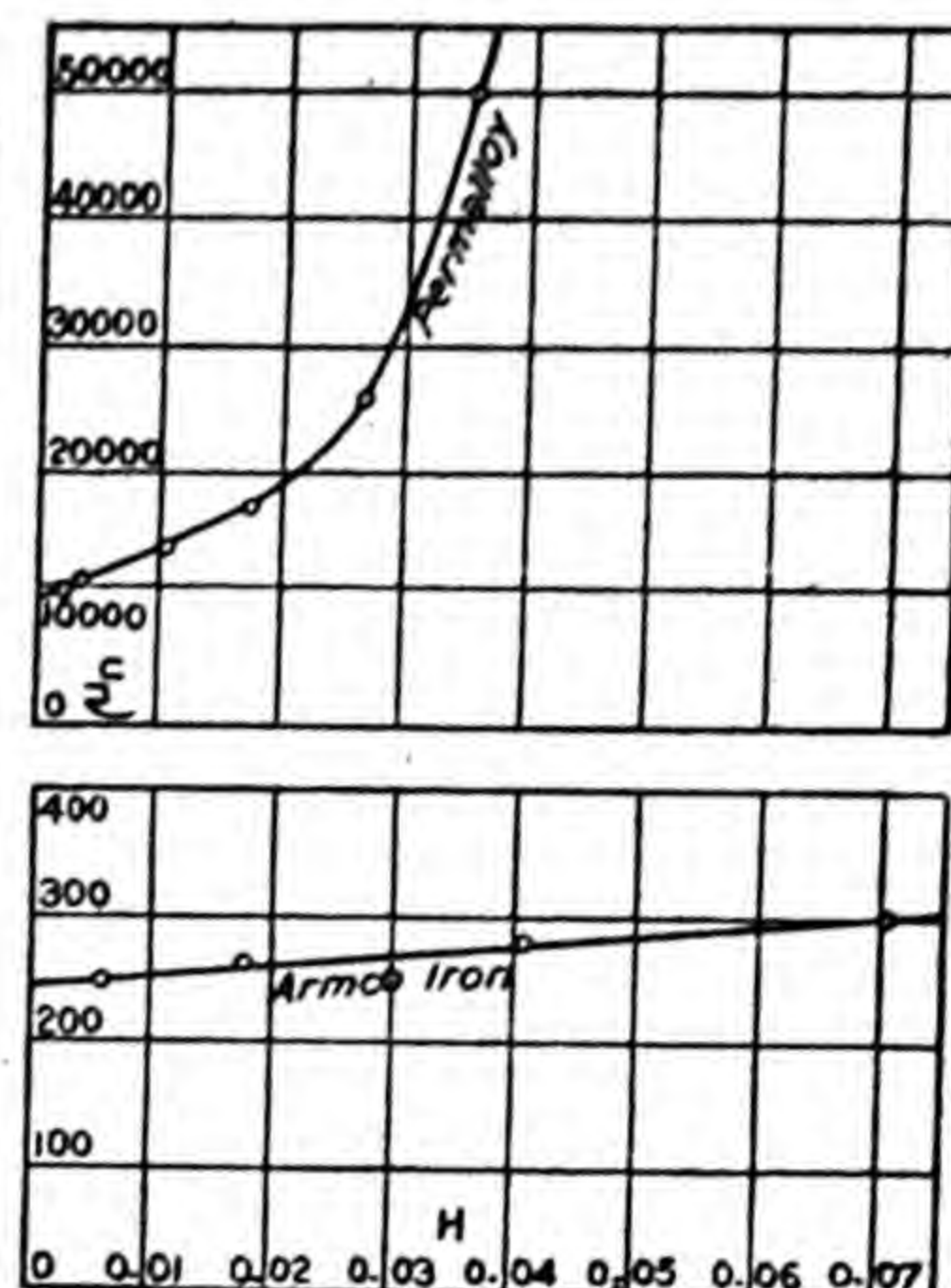


FIG. 29.—Permalloy (130): Normal permeability (4); cf. Fig. 28.

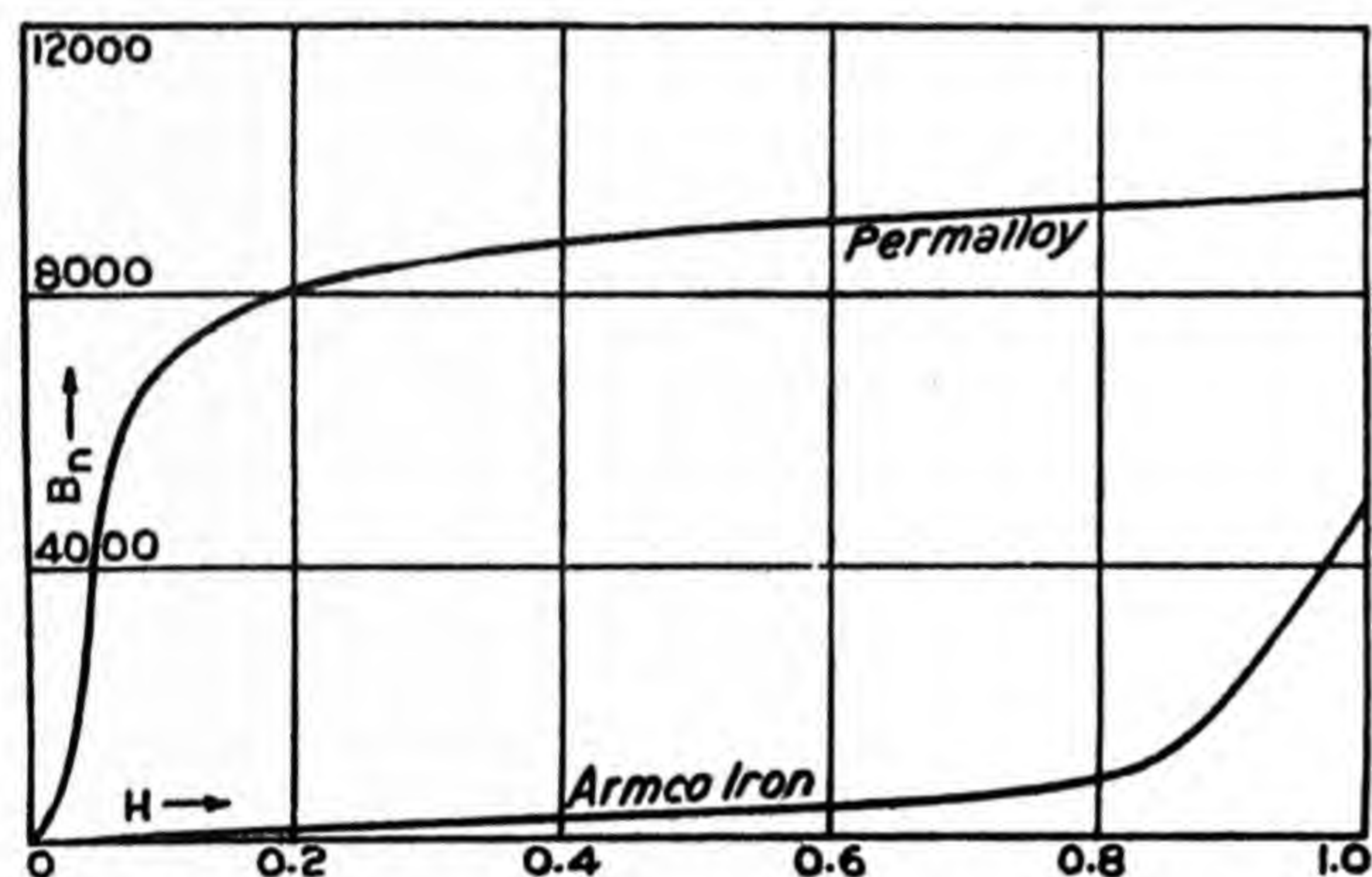


FIG. 30.—Permalloy (130): Normal induction (4); v. also Figs. 31, 32.

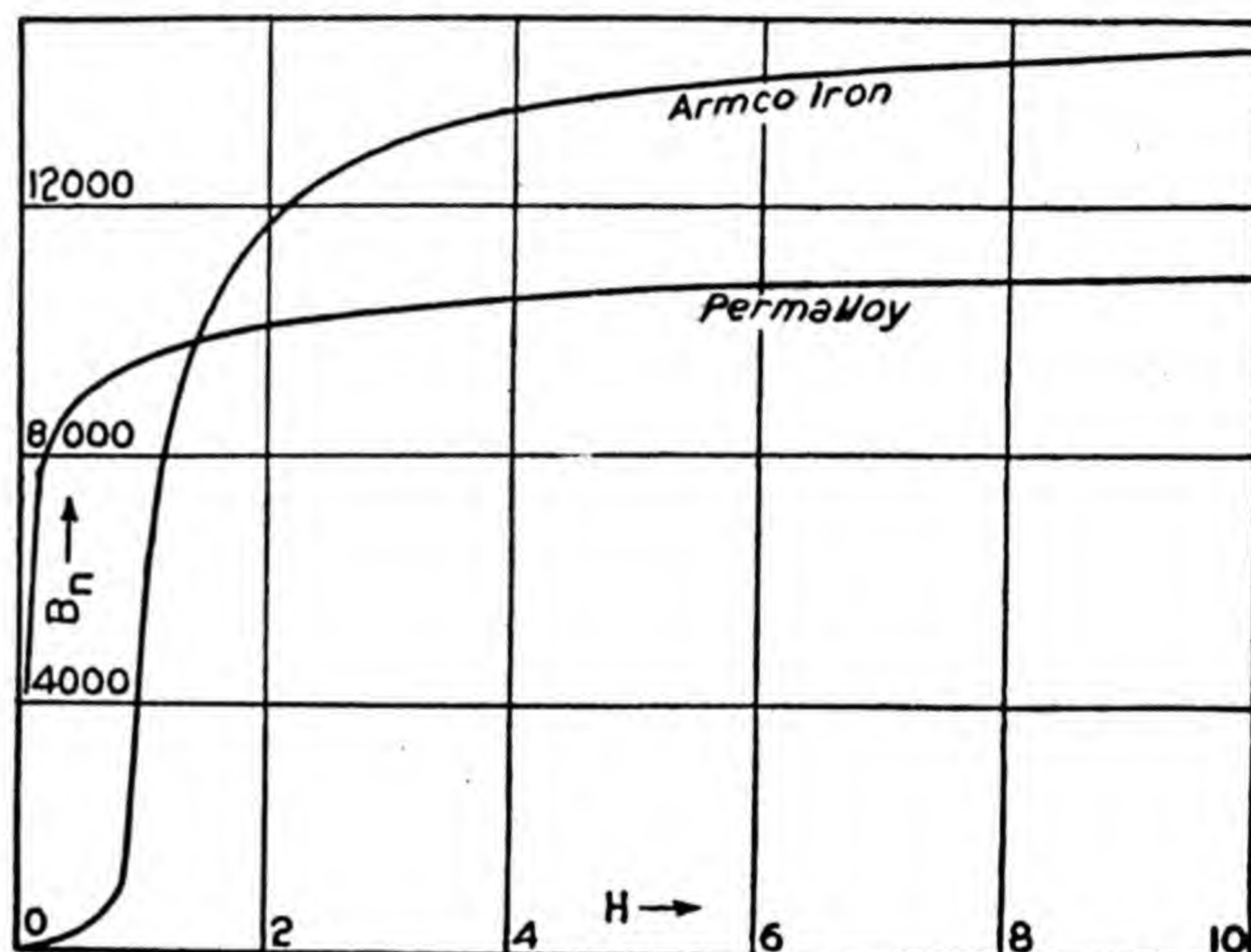


FIG. 31.—Permalloy (130): Normal induction (4); v. also Figs. 30, 32.

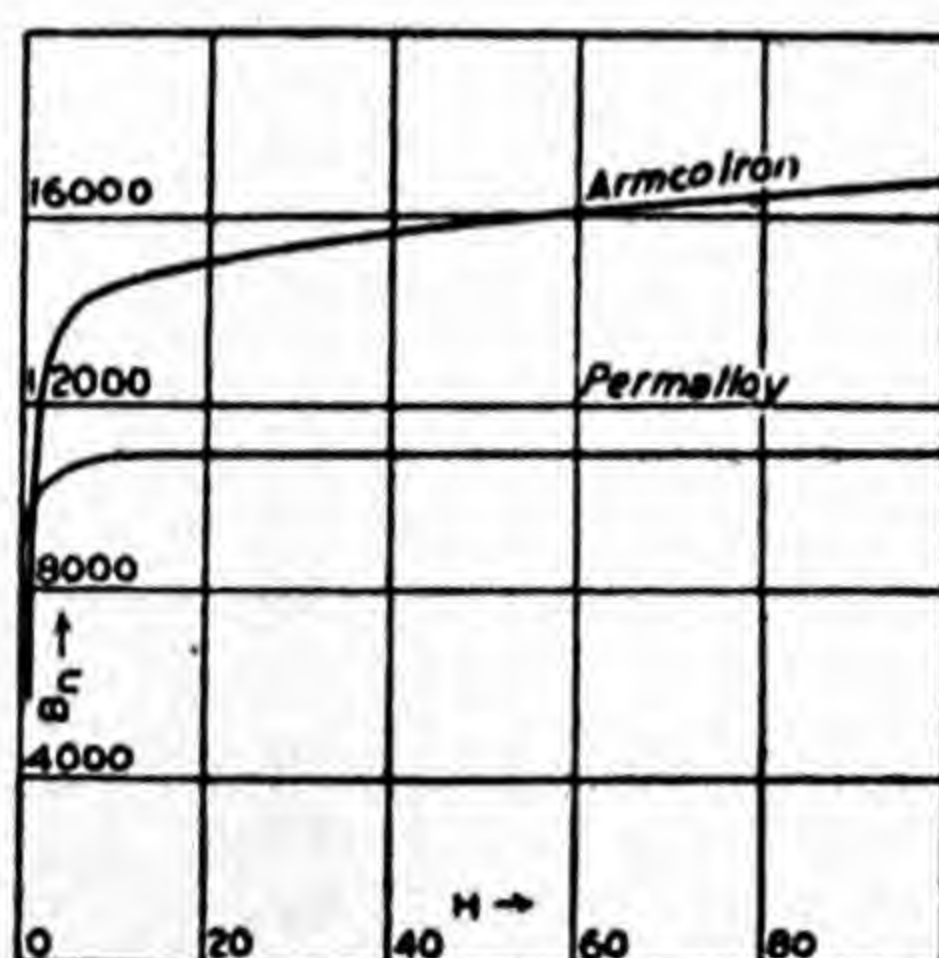


FIG. 32.—Permalloy (130): Normal induction (4); v. also Figs. 30, 31.

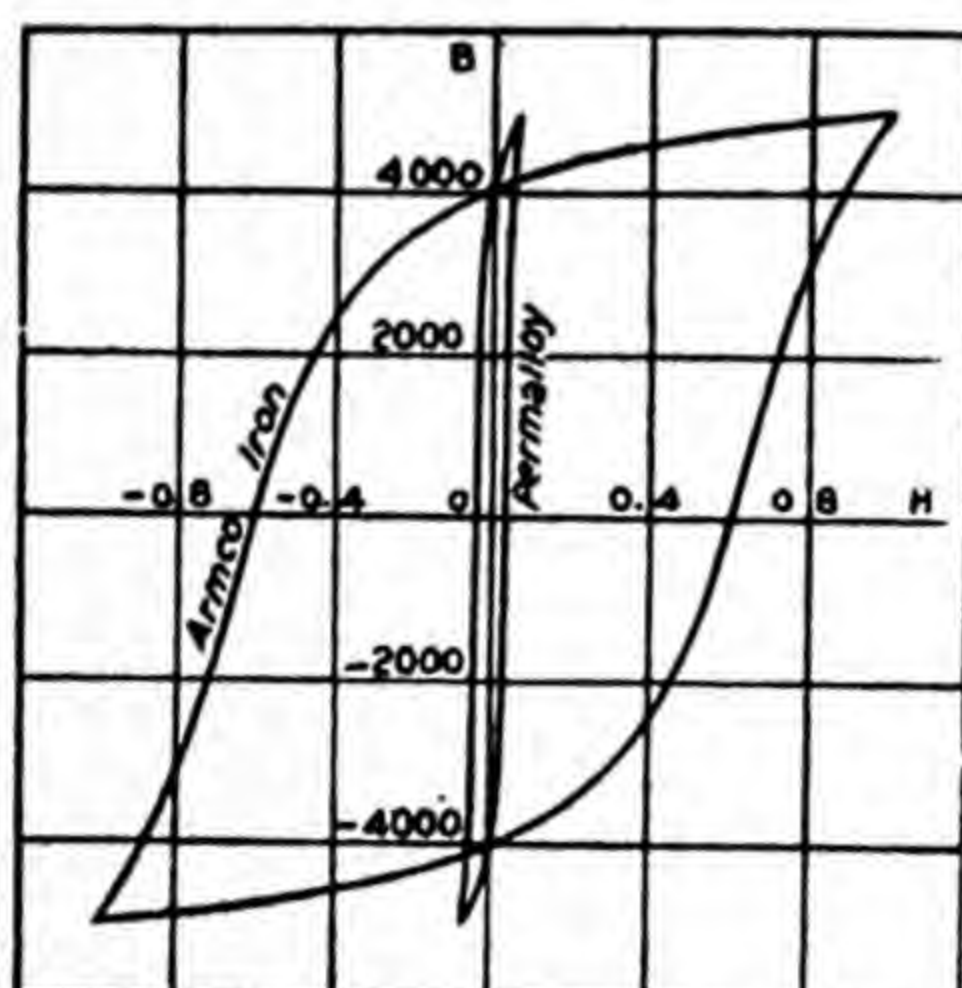


FIG. 33.—Permalloy (130): Cyclic induction (4).

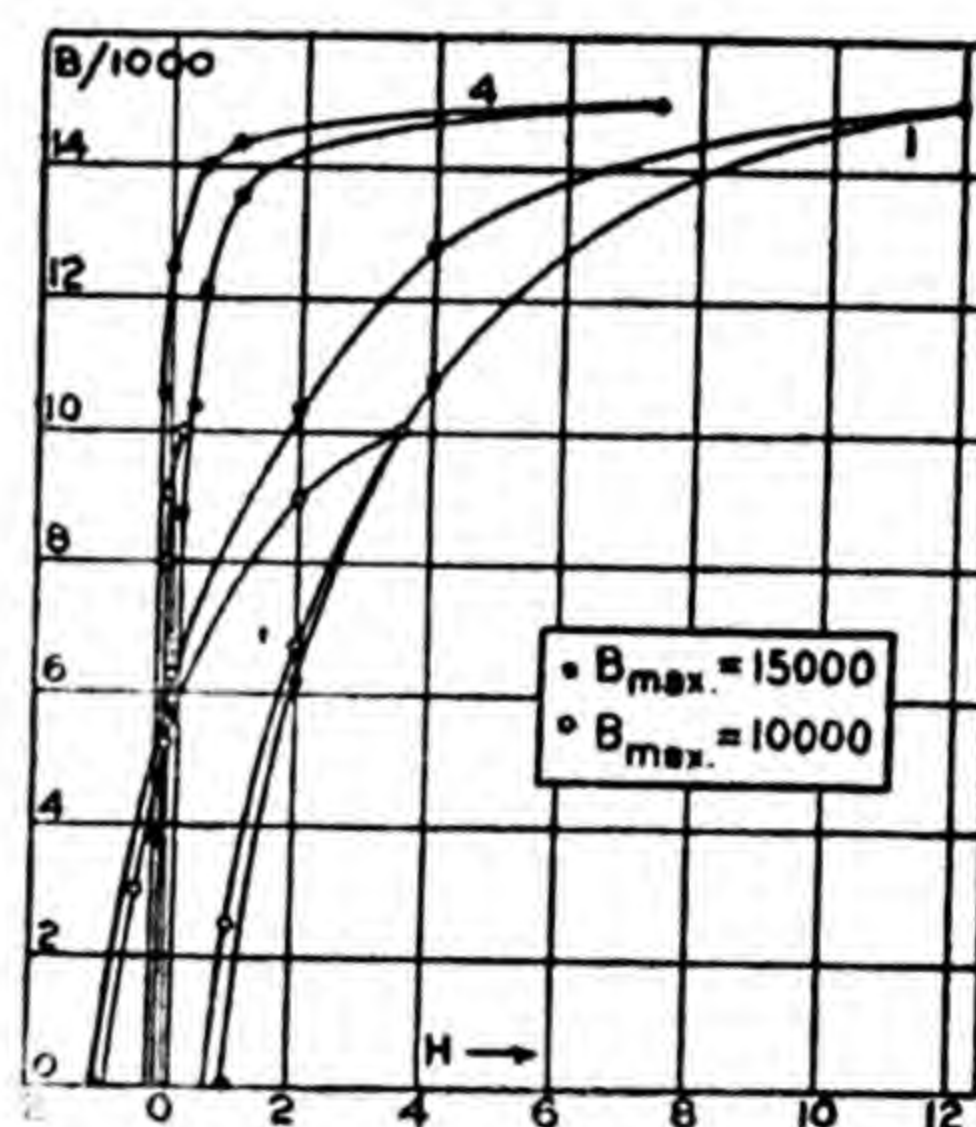

 FIG. 36.—Silicon irons: Two specimens of same Si content (4). (1) = commercial silicon steel, 3 to 4 % Si,  $W = 2160$  if  $B_{max} = 10000$ ,  $W = 4290$  if  $B_{max} = 15000$ ,  $\rho = 51.15$  microhm-cm. (4) = pure, vacuum cast, silicon iron, 3.4 % Si,  $W = 280$  if  $B_{max} = 10000$ ,  $W = 1025$  if  $B_{max} = 15000$ ,  $\rho = 48.50$  microhm-cm. Both specimens annealed; cf. Fig. 38.



TABLE 17.—(Continued from p. 396)

Key	60*	60†	61*	61†	63*	63†	67*	67†
<i>B</i> , Cyclic induction								
— 1.0	+ 6 000	— 6 550	0	— 5 200	— 3 900	— 1 750	— 3 100	+ 2 600
— 1.5	— 900	—10 480	— 3 200	— 9 730	— 6 400	— 4 800	— 5 880	— 8 300
— 2.5	— 7 100	—13 230	— 6 120	—12 400	— 9 620	— 7 980	— 8 800	—11 420
— 5	—11 350	—14 400	—10 140	—14 020	—13 280	—11 570	—12 130	—12 840
— 10	—13 880	—15 130	—13 300	—14 720	—14 900	—13 470	—13 720	—13 520
— 20	—15 200	—15 840	—14 670	—15 420	—15 680	—14 520	—14 570	—14 200
— 50	—16 520	—16 820	—15 920	—16 420	—16 640	—15 700	—15 750	—15 220
—100	—17 550	—17 880	—17 100	—17 420	—17 660	—16 770	—17 000	—16 300
—150	—18 400	—18 600	—17 950	—18 200	—18 400	—17 500	—17 900	—17 070
<i>B<sub>r</sub></i>	9 850	14 800	5 700	14 080	6 800	6 600	6 000	13 000
<i>H<sub>c</sub></i>	1.45	0.775	1.00	0.835	0.67	0.835	0.65	1.06
$\mu_n(\text{max.})$	3 470	8 480	2 680	7 700	4 870	3 560	4 450	5 700
$\mu_0$	(200)		238		435		510	
$4\pi I_{\text{obs.}}$	20 850		20 270		19 780		19 080	
$4\pi I_{\text{red.}}$	21 160		20 580		19 960		19 520	
$1000\eta_{\text{max.}}$	1.68	1.22	1.44	1.25	0.79	0.116	0.86	1.41
$\rho_{20}$	23.24		39.64		51.73		61.26	
$1000\alpha_{\text{red.}}$	2.47		1.31		0.87		0.68	
<i>d<sub>red.</sub></i>	7.815		7.719		7.640		7.597	

Key	64†	64§	<i>H</i>	64†	64§	<i>H</i>	64†	64§
<i>H</i>	$\mu_n$			<i>B</i> , Cyclic			<i>B</i> , Cyclic	
0.25	4 000	1 200	±65	±15 600	15 450	— 0.5	— 900	+ 3 150
0.5	6 700	2 200	50	15 220	15 060	— 0.75	— 4 780	0
0.75	7 400	3 330	25	14 480	14 230	— 1.0	— 6 700	— 2 250
1.0	7 000	3 600	10	13 770	13 180	— 1.5	— 8 480	— 4 650
1.5	5 790	3 540	5	13 150	11 900	— 2.5	—10 280	— 7 100
2.5	4 160	2 950	2.5	12 260	10 240	— 5	—12 100	— 9 970
5	2 450	2 020	+ 1	10 700	8 360	—10	—13 230	—12 300
10	1 330	1 240	0	7 830	6 130	—20	—14 080	—13 700
20	700	690	— 0.25	+5 600	5 140	—50	—15 220	—15 040
50	305.4	300.8	<i>B<sub>r</sub></i>	7 830	6 130	<i>H<sub>c</sub></i>	0.47	0.75
65	240.0	237.7	$\mu_n(\text{max.})$	7 500	3 630			

\* Bar;  $t_a = 800^\circ\text{C}$ . † Sheet, 0.5 mm thick;  $t_a = 800^\circ\text{C}$ . ‡ Sheet 0.4 mm thick;  $t_a = 800^\circ\text{C}$ . § Sheet 0.4 mm thick;  $t_a = 1000^\circ\text{C}$ .

Pure silicon iron (92). Electrolytic Fe, containing 0.006 to 0.01% C, 0.01% Si, was fused *in vacuo* with a ferrosilicon containing 92.23% Si, 8.50% Fe, 0.016% C. Ingots were forged into bars, heat treated, and studied; magnetic properties are improved by annealing; for  $t_a = 1100$  they are a little better than for  $t_a = 900^\circ\text{C}$ . Data for material annealed at  $1100^\circ\text{C}$  are given in Figs. 34 to 38 and the following table; for results of other heat treatments, see (92).

% Si	$\mu_n(\text{max.})$	<i>B<sub>μ</sub></i> *	$\mu_n$ †	<i>B<sub>max.</sub></i> = 10 000			<i>B<sub>max.</sub></i> = 15 000			
				<i>W</i>	<i>B<sub>r</sub></i>	<i>H<sub>c</sub></i>	<i>W</i>	<i>B<sub>r</sub></i>	<i>H<sub>c</sub></i>	$\rho_{20}$
0.001	22 800	8 000	21 300	665	9 300	0.20	1 860	13 300	0.24	9.84
0.001	25 800	9 000	25 600	707	9 300	0.23	1 451	12 700	0.28	9.85
0.01	29 000	9 000	28 670	707	9 600	0.21	1 604	14 300	0.31	9.90
0.040	27 000	10 000	27 000	700	9 440	0.23	1 660	14 480	0.32	10.50
0.064	36 800	9 000	36 300	502	9 500	0.16	1 336	14 300	0.25	10.67
0.068	44 200	9 000	43 500	407	9 480	0.13	1 214	14 200	0.22	10.78
0.091	45 250	9 000	43 500	394	9 500	0.13	929	14 300	0.17	10.96
0.148	66 500	6 500	41 700	286	9 080	0.09	916	12 000	0.16	11.80
0.205	30 200	9 000	29 500	649	9 300	0.20	1 526	14 480	0.27	12.50
0.242	36 500	7 500	33 000	436	9 700	0.13	1 346	14 500	0.21	13.40
0.309	44 800	9 000	43 500	445	9 600	0.13	1 412	14 500	0.24	14.40
0.400	22 500	9 000	22 000	725	9 440	0.21	1 820	14 480	0.32	15.30
0.472	31 150	6 200	25 000	535	9 300	0.16	1 358	14 200	0.21	16.57
0.563	25 000	9 000	25 000	601	9 200	0.20	1 624	14 320	0.28	17.50
0.673	28 000	7 000	24 500	468	9 200	0.13	1 636	13 670	0.23	19.10
0.698	20 350	8 000	19 600	780	9 300	0.25	2 220	14 400	0.40	19.60
0.822	30 800	9 500	30 300	542	9 200	0.18	1 765	14 100	0.35	21.25
1.71	30 150	6 500	24 700	440	8 700	0.12	1 292	12 000	0.22	33.25
1.740	33 000	7 000	26 300	416	9 200	0.13	1 112	12 600	0.19	31.00
2.73	46 800	9 500	46 000	404	9 100	0.13	1 260	13 300	0.23	42.00
3.40	63 300	6 500	46 500	280	9 100	0.08	1 025	12 400	0.15	48.50

Continued on p. 400



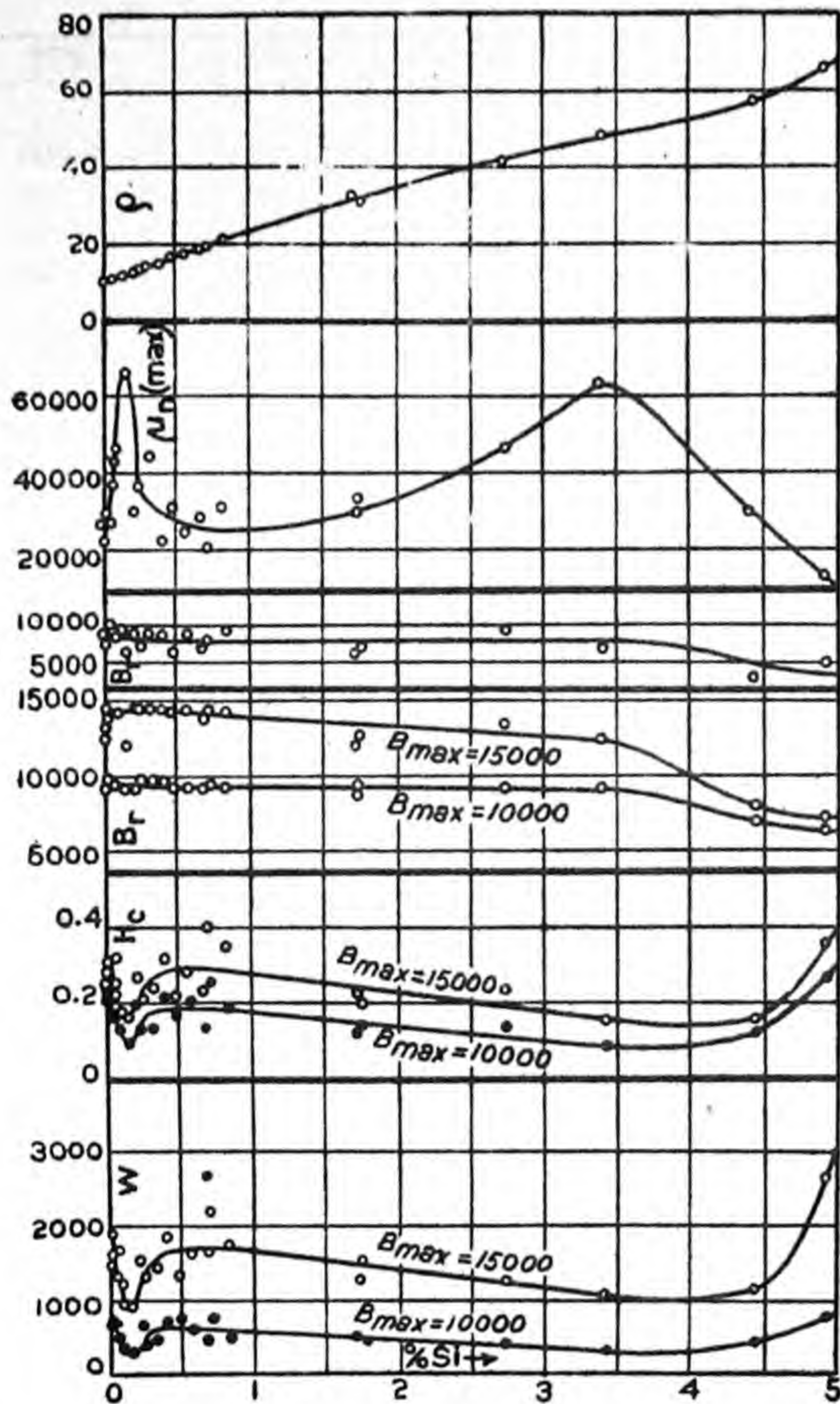


FIG. 34.—Silicon irons: Effect of Si (92).

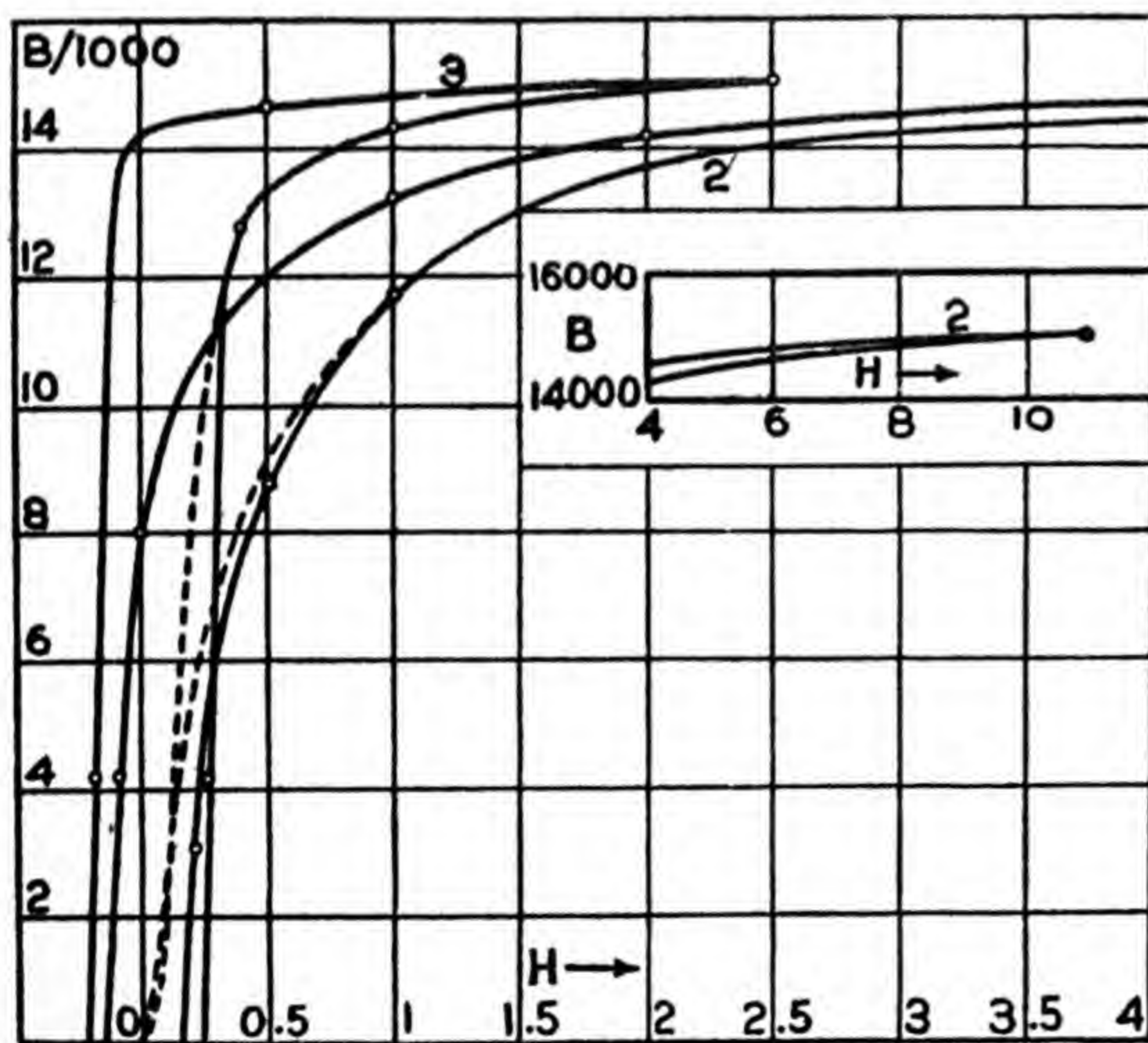
 Unit of  $\rho = 1$  microhm-cm; of other quantities = 1 cgs unit.


FIG. 37.—Silicon irons: Two pure specimens of different Si content (92).

Both specimens are pure, vacuum cast, silicon irons annealed from  $1100^{\circ}\text{C}$ . (2) contains 4.44% Si,  $W = 405$  if  $B_{\text{max}} = 10\,000$ ,  $W = 1171$  if  $B_{\text{max}} = 15\,000$ ,  $\rho = 57.40$  microhm-cm. (3) contains 0.048% Si,  $W = 407$  if  $B_{\text{max}} = 10\,000$ ,  $W = 1\,214.5$  if  $B_{\text{max}} = 15\,000$ ,  $\rho = 10.78$  microhm-cm; cf. Fig. 38.

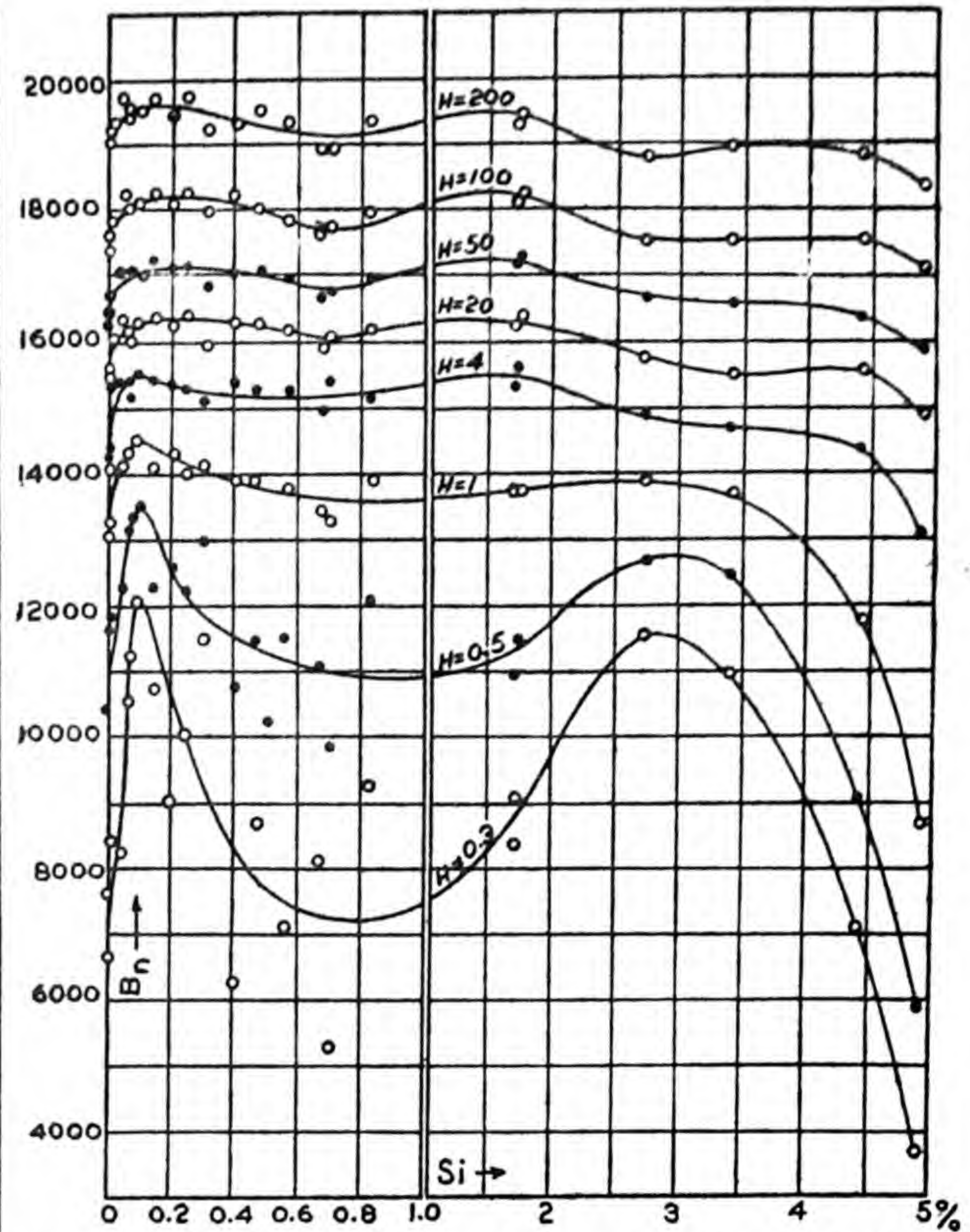


FIG. 35.—Silicon irons: Effect of Si upon normal induction (92).

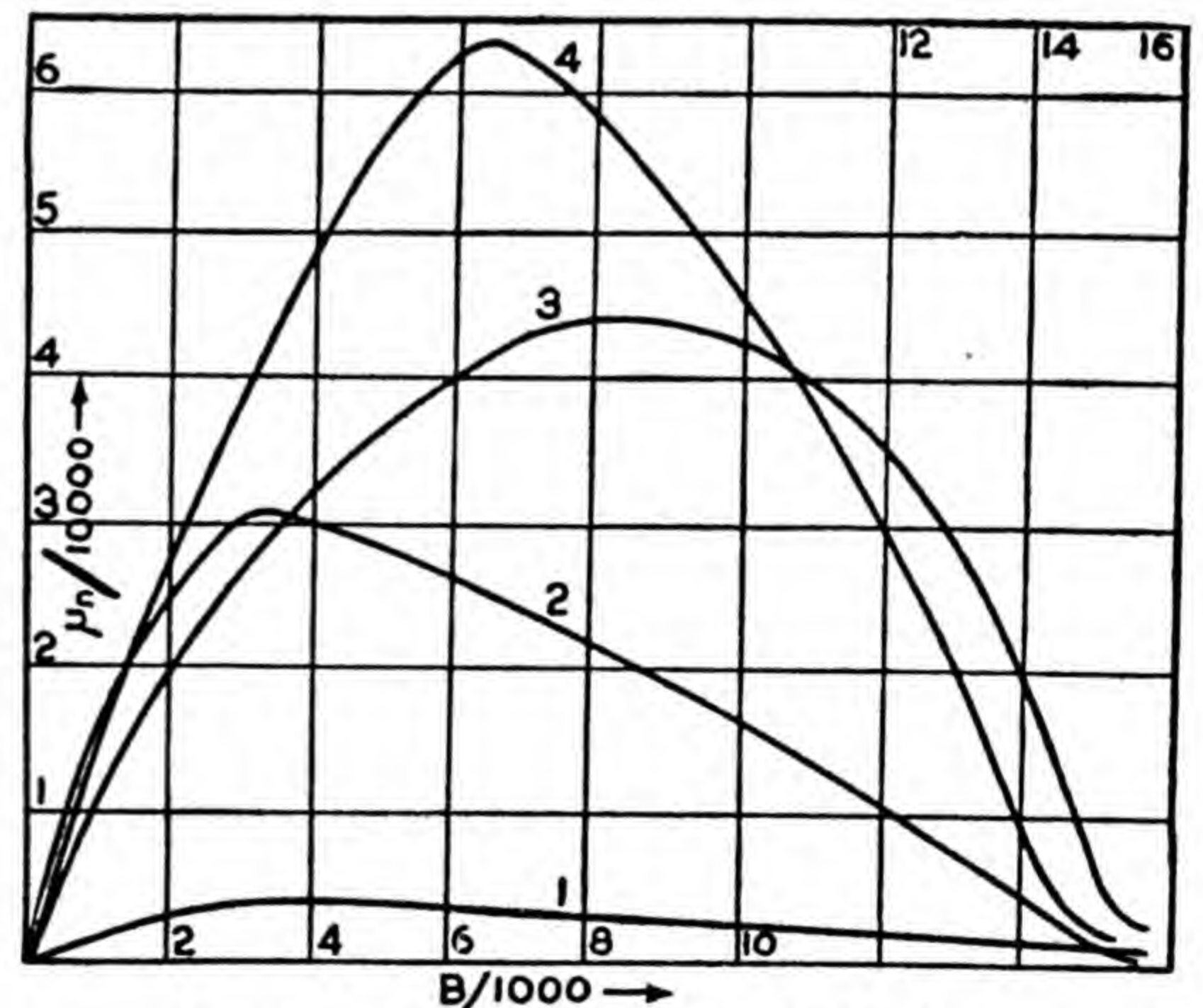


FIG. 38.—Silicon irons: Permeability (92).

Specimen (1) is commercial silicon steel, 3 to 4% Si, annealed; (2), (3), and (4) are pure, vacuum cast, silicon irons annealed from  $1100^{\circ}\text{C}$ , and contain, respectively, 4.44, 0.048, and 3.4% Si. Same materials as for Figs. 36, 37, and section on silicon irons in Table 17, p. 396.



TABLE 17.—(Continued from p. 398)

% Si	$\mu_n(\text{max.})$	$B_{\mu}^*$	$\mu_n^{\dagger}$	$B_{\text{max.}} = 10\ 000$			$B_{\text{max.}} = 15\ 000$			
				$W$	$B_r$	$H_c$	$W$	$B_r$	$H_c$	$\rho_{25}$
3.55†	36 000	7 500	29 500	419	8 920	0.13	1 157	12 000	0.21	48.50
4.39†	25 700	6 000	15 400	591	8 300	0.20	1 819	10 200	0.25	56.10
4.44†	30 200	3 000	15 900	405	7 000	0.12	1 171	8 000	0.15	57.40
4.92†	12 200	5 000	7 040	780	6 300	0.26	2 620	7 100	0.35	66.20
0.15‡	66 500	6 500		286			916			11.8
3.40§	63 300	6 500		280			1 025			48.5

\* Value of  $B$  at which  $\mu_n = \mu_n(\text{max.})$ .† Value for  $B = 10\ 000$ .‡ These 2 bars were annealed in N; inferior to those annealed in *vacuo*.

§ These are best two alloys obtained.

68, Cast iron (2<sup>d</sup>). C = 3.109, Si = 3.270, Mn = 0.560, P = 1.050, S = 0.061%; see Tables 4, 9, 11, 68, 69.V, Vanadium iron (4<sup>3</sup>) 135. Pure Fe was fused with ferrovanadium; the product contained 3.5% V, 0.22% Mn, 0.60% C of which 0.50% was combined, no Cr, traces of Si. Data refer to 4 states: (1) as cast; (2) annealed from 900 or 950°; (3) quenched at 900 or 950°; and (4) reannealed from 900 or 950°C. The hysteresis loss per cm<sup>3</sup> per cycle is  $W = \eta B_{\text{max.}}^2$ .

Cast		Annealed		Quenched		Reannealed	
$H$	$\mu_n$	$H$	$\mu_n$	$H$	$\mu_n$	$H$	$\mu_n$
2.8	71	2.8	64	2.8	36	2.8	64
4.3	84	4.3	72	5.8	41	5.8	75
5.8	95	7.2 <sup>c</sup>	76	8.7	46	7.2 <sup>c</sup>	86.5
7.2 <sup>c</sup>	120	10.1	104	11.6	46.5	8.7	95
8.7	171	13.0	138	14.5	49	10.1	101.6
10.1	225	14.5	163	17.5	49.1	11.6	106.1
11.1	251	17.5	232	23.5	49.8	14.5	120.7
13.5	348	20.5	273	26.5	50.0	17.5	146.3
14.5	368	23.5	298	29.5	55.5	20.5	163.7
17.5	422	26.5	309	32.6	57.7	23.5	178.9
20.5	424	29.5	304	38.7	69.8	26.5	203.8
23.5	413	44.9	253	41.8	73.0	29.5	210.8
26.5	408	60.1	208	44.9	80.2	38.7	214.5
29.5	387	75.6	174	47.9	83.5	44.9	210.0
44.9	285	91.5	148.6	50.9	90.4	60.1	181.4
60.1	226.3	106.4	131.3	53.9	98.3	75.6	154.9
75.6	186.5	121.7	117.9	57.0	102.8	85.1	142.0
91.5	157.4	140.0	104.6	60.1	109.8	91.5	135.0
121.7	122.4			66.2	116.9	106.4	120.4
				69.5	122.3	121.7	107.5
				75.6	120.0	140.0	95.4
				91.5	113.7		
				106.4	104.1		
				121.7	95.3		
				140.0	85.0		

135 (Cast), Cyclic induction,  $\eta = 0.0132$ ;  $\epsilon = 1.6$ 

$H$	$B$	$H$	$B$	$H$	$B$	$H$	$B$	$H$	$B$
14.5	5 280	29.5	11 400	44.9	12 440	60.1	13 200	91.5	14 100
11.6	5 120	26.5	11 300	41.8	12 300	47.9	12 950	75.6	13 900
10.1	5 010	23.5	11 200	38.7	12 250	41.8	12 800	60.1	13 600
8.7	4 890	20.5	11 000	35.6	12 200	35.6	12 600	44.9	13 200
7.2	4 770	17.5	10 900	32.6	12 100	29.5	12 400	32.6	12 900
5.8	4 650	14.5	10 800	29.5	12 000	23.5	12 220	20.5	12 400
4.3	4 470	11.6	10 600	17.5	11 500	17.5	12 000	14.5	12 100
2.8	4 040	8.7	10 400	14.5	11 400	11.6	11 650	8.7	11 800
+ 1.4	4 140	5.8	10 200	11.6	11 280	5.8	11 200	+ 2.8	11 400
- 1.4	3 810	2.8	9 800	8.7	11 090	+ 2.8	11 000	- 2.8	10 700
- 2.8	3 710	+ 1.4	9 700	5.8	10 750	- 2.8	10 200	- 5.8	9 800
- 4.3	3 330	- 1.4	9 300	+ 2.8	10 500	- 5.8	9 300	- 8.7	7 800
- 5.8	2 780	- 2.8	9 000	- 2.8	9 760	- 8.7	6 700	- 10.1	5 700
- 7.2	1 570	- 5.8	8 100	- 5.8	8 700	- 10.1	4 300	- 11.6	+ 3 000
- 8.7	+ 460	- 7.2	7 500	- 8.7	6 600	- 11.6	+ 1 600	- 14.5	- 2 900
- 10.1	- 1 550	- 8.7	6 500	- 10.1	4 000	- 13.0	- 800	- 17.5	- 6 300
- 11.6	- 2 430	- 10.1	3 400	- 11.6	+ 800	- 14.5	- 3 750	- 23.5	- 9 700
- 14.5	- 5 280	- 11.6	+ 400	- 13.0	- 1 700	- 17.5	- 6 600	- 29.5	- 11 000
		- 13.0	- 2 300	- 14.5	- 4 250	- 20.5	- 8 580	- 44.9	- 12 400



TABLE 17.—(Continued)

<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>
		-14.5	- 4 500	-17.5	- 6 800	-23.5	- 9 700	-60.1	-13 000
		-16.0	- 5 000	-20.5	- 8 600	-29.5	-11 100	-75.6	-13 600
		-17.5	- 7 400	-26.5	-10 400	-44.9	-12 400	-91.5	-14 100
		-20.5	- 9 100	-38.6	-11 700	-60.1	-13 200		
		-23.5	-10 300	-44.9	-12 440				
		-26.5	-10 700						
		-29.5	-11 400						
<i>B<sub>r</sub></i>	4 000	9 500		10 300		10 800		11 200	
<i>H<sub>c</sub></i>	9.3	11.6		12.0		12.5		13.0	
<i>W</i>	12 100	40 930		46 950		51 870		58 870	

135 (Annealed), Cyclic induction,  $\eta = 0.0164$ ;  $e = 1.6$ 

<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>
15.1	2 690	29.5	8 970	44.9	11 250	60.1	12 350	91.5	13 600
10.7	2 495	26.5	8 850	38.7	11 060	50.9	12 100	78.7	13 380
9.0	2 330	23.5	8 625	32.6	10 830	41.8	11 840	69.5	13 220
6.0	2 070	20.5	8 540	29.5	10 720	35.6	11 650	60.1	12 990
4.5	1 920	17.5	8 470	23.5	10 430	29.5	11 390	47.9	12 630
3.0	1 820	14.5	8 180	17.5	10 100	23.5	11 060	38.7	12 310
+ 1.5	1 650	11.6	7 890	14.5	9 930	17.5	10 760	29.5	11 940
- 1.5	1 330	8.7	7 770	11.6	9 725	11.6	10 320	17.5	11 250
- 3.0	1 120	5.8	7 500	8.7	9 460	5.8	9 770	8.7	10 550
- 4.5	856	2.8	7 170	5.8	9 190	+ 2.8	9 420	+ 2.8	9 690
- 6.0	540	+ 1.4	6 990	+ 2.8	8 870	- 2.8	8 580	- 2.8	8 810
- 7.5	+ 150	- 1.4	6 610	- 2.8	8 080	- 5.8	7 650	- 5.8	8 180
- 9.0	- 330	- 2.8	6 350	- 5.8	7 140	- 8.7	6 740	- 8.7	7 300
-10.0	- 630	- 5.8	5 740	- 8.7	6 150	-10.1	6 250	-11.6	5 910
-10.6	- 780	- 8.7	4 370	-11.6	4 780	-11.6	5 400	-13.0	5 100
-11.1	-1 100	-11.6	+3 220	-14.5	+ 2 450	-13.0	4 420	-14.5	4 150
-12.0	-1 250	-14.5	- 140	-17.5	- 1 550	-14.5	3 080	-17.5	+ 200
-15.1	-2 690	-17.5	-3 880	-20.5	- 4 610	-16.0	+ 1 530	-20.5	- 3 000
		-20.5	-6 720	-26.5	- 7 470	-17.5	- 90	-22.0	- 4 700
		-23.5	-7 570	-29.5	- 9 060	-20.5	- 4 120	-23.5	- 5 700
		-26.5	-8 220	-35.6	-10 350	-29.5	- 9 060	-26.5	- 7 900
		-29.5	-8 970	-44.9	-11 250	-44.9	-11 260	-29.5	- 8 700
						-60.1	-12 350	-32.6	- 9 300
								-44.9	-11 300
								-60.1	-12 900
								-75.6	-13 260
								-91.5	-13 600
<i>B<sub>r</sub></i>	1 400	6 800		8 600		9 000		9 200	
<i>H<sub>c</sub></i>	8.1	14.5		16.7		17.3		17.8	
<i>W</i>	4 973	35 160		50 160		57 890		67 080	

135 (Quenched), Cyclic induction,  $\eta = 0.0096$ ;  $e = 1.7$ 

<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>	<i>H</i>	<i>B</i>
14.5	672	29.5	1 600	44.9	3 530	60.1	6 500	91.5	10 400
8.7	454	20.5	1 230	29.5	2 950	53.9	6 340	75.6	10 060
5.8	237	14.5	1 000	23.5	2 700	44.9	6 190	60.1	9 720
2.8	212	11.6	840	17.5	2 440	29.5	5 500	44.9	9 465
+ 1.4	165	8.7	730	11.6	2 130	14.5	4 820	29.5	8 880
- 1.4	+ 56	5.8	600	8.7	1 850	5.8	4 400	17.5	8 430
- 2.8	- 38	+ 2.8	430	+ 2.8	1 680	+ 2.8	4 250	11.6	8 200
- 5.8	-217	- 2.8	200	- 2.8	1 380	- 2.8	3 930	5.8	7 920
- 8.7	-381	- 5.8	+ 40	- 5.8	1 180	- 5.8	3 580	+ 4.3	7 870
-11.6	-520	- 8.7	- 225	- 8.7	890	- 8.7	3 220	- 4.3	7 400
-14.5	-672	-11.6	- 440	-11.6	680	-11.6	2 910	- 5.8	7 000
		-14.5	- 590	-14.5	440	-14.5	2 660	-11.6	6 500
		-17.5	- 810	-17.5	+ 180	-17.5	2 400	-17.5	6 050
		-20.5	-1 020	-20.5	- 440	-20.5	2 190	-23.5	5 420
		-23.5	-1 210	-23.5	- 750	-23.5	1 775	-29.5	4 630
		-29.5	-1 600	-26.5	-1 130	-26.5	1 400	-35.6	3 470
				-29.5	-1 450	-29.5	830	-38.7	2 590



## INTERNATIONAL CRITICAL TABLES

TABLE 17.—(Continued)

H	B	H	B	H	B	H	B	H	B
				-35.6	-2 450	-32.6	+ 140	-41.8	+ 1 580
				-38.7	-2 830	-35.6	- 560	-44.9	- 200
				-44.9	-3 530	-41.8	-2 380	-50.9	- 3 210
						-44.9	-3 330	-53.9	- 4 720
						-47.9	-4 270	-60.1	- 7 370
						-53.9	-5 400	-75.6	- 9 600
						-60.1	-6 500	-91.5	-10 400
$B_r$	110	315		1 500		4 000		7 600	
$H_c$	2.5	6.5		17.5		33.5		44.5	
$W$	231	1 464		13 610		49 490		114 100	

135 (Reannealed), Cyclic induction,  $\eta = 0.02$ ;  $e = 1.6$ 

H	B	H	B	H	B	H	B	H	B
14.5	1 750	29.5	6 220	44.9	9 425	60.1	10 900	91.5	12 350
10.1	1 470	26.5	6 080	38.7	9 295	53.9	10 720	75.6	12 020
8.7	1 370	23.5	5 920	32.6	8 930	44.9	10 415	60.1	11 710
5.8	1 170	20.5	5 710	29.5	8 875	38.7	10 185	44.9	11 130
2.8	940	17.5	5 520	26.5	8 745	32.6	9 920	35.6	10 780
+ 1.4	785	14.5	5 350	23.5	8 475	26.5	9 620	29.5	10 500
- 1.4	595	11.6	5 100	20.5	8 290	20.5	9 300	23.5	10 280
- 2.8	+ 380	8.7	4 900	17.5	8 000	14.5	8 940	17.5	9 820
- 5.8	- 70	5.8	4 620	14.5	7 900	8.7	8 530	11.6	9 430
- 8.7	- 735	2.8	4 300	11.6	7 675	+ 2.8	7 600	5.8	8 450
-10.1	-1 010	+ 1.4	4 170	8.7	7 465	- 2.8	6 750	+ 2.8	8 140
-11.6	-1 280	- 1.4	3 830	5.8	7 215	- 8.7	5 350	- 2.8	7 350
-14.5	-1 750	- 2.8	3 600	+ 2.8	6 915	-14.5	3 580	- 5.8	6 940
		- 5.8	2 980	- 2.8	5 885	-17.5	2 360	- 8.7	6 070
		- 8.7	1 930	- 5.8	5 275	-20.5	+ 1 020	-11.6	5 270
		-11.6	+ 190	- 8.7	4 425	-23.5	- 1 180	-13.0	4 950
		-14.5	- 180	-11.6	3 500	-29.5	- 5 700	-14.5	4 360
		-17.5	-1 650	-14.5	2 530	-32.6	- 7 400	-17.5	3 200
		-20.5	-2 990	-17.5	+1 415	-35.6	- 8 315	-20.5	+ 1 740
		-23.5	-4 280	-20.5	- 275	-41.8	- 9 330	-23.5	- 90
		-26.5	-5 130	-23.5	-2 655	-47.9	-10 330	-26.5	- 2 470
		-29.5	-6 220	-26.5	-4 665	-60.1	-10 900	-29.5	- 4 850
				-29.5	-5 945			-32.6	- 6 680
				-35.6	-8 145			-35.6	- 7 960
				-38.7	-8 500			-44.9	- 9 610
				-44.9	-9 425			-60.1	-11 170
								-75.6	-11 990
								-91.5	-12 350
$B_r$	650	3 950		6 500		7 100		7 700	
$H_c$	5.5	14.0		20.0		22.0		23.5	
$W$	1 919	20 810		46 670		57 750		67 740	

W, Tungsten iron. See p. 385 and Tables 12, 13, 15, 16 (84, 136 to 144).

## Cobalt

TABLE 18.—MAGNETIC PROPERTIES

For properties in very intense fields, see Table 4. Composition and heat treatment of specimens are not stated. Annealed Co is magnetically much harder than unannealed cast Co. Above 700°C, Co is very hard and it is not certain that saturation has been attained at these temperatures. For ferrocobalts, see Table 17 (Co); for nickel-cobalts, see Table 20 (Co).

1461 (<sup>53</sup>) ( $\sigma_\infty$  extrapolated from data for  $H = 13 500$ )

$t$	$\sigma_\infty$	$t$	$\sigma_\infty$	$t$	$\sigma_\infty$	$t$	$\sigma_\infty$
17	165.5	1069	71.3	+ 17	165.5	641	140.6
510	149.2	1016	88.2	-188	167.9	437	152.7
693	136.9	804	125.3	+ 17	165.5	362	156.1
844	120.5	918	109.1	1149	17.9	205	160.9
971	99.4	614	142.9	1133	32.1	324	156.9
1090	62.5	470	151.0	1144	20.6		
1067	72.2	748	131.8	16	165.5		



TABLE 18.—(Continued)

146/II <sub>c</sub> (34)				146/II <sub>a</sub> , Annealed at 1000° (34)			
20 0°C		-186°C		18 6°C		-186°C	
H	I <sub>n</sub>	H	I <sub>n</sub>	H	I <sub>n</sub>	H	I <sub>n</sub>
5.1	72	3.90	28	4.37	6	7 60	9
10.7	170	10.57	122	13.53	26	16.23	20
13.9	247	22.65	277	25.25	67	39.0	64
22.8	371	39.3	427	36.59	115	57.8	102
35.7	497	74.7	608	52.5	171	80.0	148
54.5	628	101.9	690	86.7	257	119.6	221
85.9	749	206.6	848	122.3	320	167.4	282
147.7	865	281.1	911	221.8	433	248.4	358
244.3	953	357	956	354	532	347	426
392	1027	449	999	445	583	496	504
467	1047	570	1038	527	613	561	543
610	1088	668	1063	699	687	702	589

146/III <sub>c</sub> , Fused in arc, and cast (66)									
22°C		414°C		698°C		874°C		1065°C	
H	σ <sub>n</sub>	H	σ <sub>n</sub>	H	σ <sub>n</sub>	H	σ <sub>n</sub>	H	σ <sub>n</sub>
725	102.4	460	119.2	140	87.5	215	83.4	1165	21.4
1955	139.6	2055	145.8	855	124.1	1300	97.9	2400	26.8
2985	149.1	3135	146.3	1620	124.3	2015	97.9	3060	30.0
3450	153.2	3930	146.4	2115	125.2	2510	98.7	3570	29.7
3955	154.6	4515	146.4	2400	124.9	3915	97.9	4010	29.4
4270	155.2								

## Nickel

TABLE 19.—MAGNETIC PROPERTIES

For properties in very weak and in very intense fields, and for variation with temperature in weak fields, see Tables 3, 4 (148, 150). For impurities, see Table 1; cf. Figs. 41, 42, 43

Key	Remarks
146.1	Heraeus. Fused in vacuum. Composition: 99.91% Ni, 0.01% Fe, 0.03% Cu, 0.05% nonmagnetic impurities. Data are corrected for effect of the impurities. At $H = 18\,550$ , $\sigma_{17^\circ\text{C}} = 54.59$ ; from an experimental study of the laws of approach to absolute saturation as $H$ and $T$ are varied, and by an extrapolation from $H = 18\,550$ and $T = 100^\circ\text{K}$ to $H = \infty$ and $T = 0^\circ\text{K}$ , it was found that $\sigma_\infty = 57.53$ ; hence $\sigma_\infty \times \text{atomic weight} = 3\,376.4 = 3 \times 1\,125.4$ ; that is, the magnetic moment of the Weiss magneton is 1125.4, cf. 1.1, Table 6, p. 378, also p. 345 (80).
147	Very pure. Fused in H in electric furnace; heated to $650^\circ\text{C}$ , cooled slowly to $350^\circ\text{C}$ , then brought to temperature at which magnetization was measured. In general, data are accurate to 0.1 or 0.2%, but do not represent the properties of any other specimen, even though pure, more closely than 1 or 2%. If $480^\circ\text{C} < t < 880^\circ\text{C}$ , $\sigma = 0.00552H/(t - 376)$ (39). At $18^\circ\text{C}$ , $\sigma_\infty = 54.5$ (73), $d\sigma_\infty/dt = 0.00053\sigma_\infty$ (81). For $H = 18\,000$ , $\sigma_{20.3^\circ\text{K}} = 1.051\sigma_{19.5^\circ\text{C}}$ , correction being made for thermal expansion (83).
149	Ni = 99.15%; $\mu_n(\text{max.}) = 1\,120$ ; $I_\infty = 509$ .
151	Contains 1.5% Co; annealed; variation of $I'_t$ with $t$ determined as for specimen 17/II in Table 5.
153	Composition not stated; 153/III <sub>c</sub> is magnetically soft; 153/III <sub>a</sub> is very hard.

147 σ, Specific magnetization (81); see also Fig. 39

$t$	H	1 000	2 000	4 000	8 000	12 000	18 000	t	σ <sub>t</sub>
20.0		53.70							
53.8			54.09	54.43	54.55	54.63	54.73	18.4	54.5
79.3					53.48	53.53	53.63	53.8	53.4
104.0					52.63	52.68	52.76	79.3	52.4
127.9					51.55	51.63	51.06	104.0	51.4
151.0					50.44	50.51	50.62	127.9	50.2
173.3					49.09	49.17	49.30	151.0	49.0
184.3					47.74	47.83	47.97	173.3	47.5
					47.02	47.07	47.23		



TABLE 19.—(Continued)

$t$	$H$	1 000	2 000	4 000	8 000	12 000	18 000	$t$	$\sigma_s$
195.1				45.94	46.13	46.25	46.34	195.1	45.9
205.7					45.25	45.38	45.56		
216.3					44.28	44.40	44.57	216.3	44.0
226.7					43.26	43.39	43.60		
237.1					42.17	42.32	42.53	237.3	41.9
247.3					41.07	41.19	41.42		
257.0					39.81	39.96	40.14	257.0	39.5
267.5					38.43	38.62	38.90		
277.5		36.30	36.50	36.74	36.99	37.21	37.51	277.5	36.6
281.5					36.48	36.61	36.94		
285.4					35.71	35.93	36.27		
289.3					35.06	35.28	35.64		
293.2					34.35	34.59	34.94		
297.1					33.61	33.86	34.28		
301.0			32.28	32.54	32.88	33.15	33.52	301.0	32.3
304.9					32.06	32.36	32.78		
308.8				30.83	31.24	31.58	32.00		
312.7				29.94	30.37	30.71	31.14		
316.5		28.30	28.65	29.00	29.46	29.87	30.26	316.5	28.7
320.3				27.95	28.44	28.82	29.33		
324.2				26.85	27.36	28.28	28.35		
328.0			25.31	25.70	26.28	26.74	27.35		
331.8			24.00	24.39	25.04	25.56	26.28		
335.6		22.08	22.40	22.91	23.66	24.27	25.04	333.7	23.1
339.4		20.42	20.78	21.36	22.21	22.86	23.75		
343.1		18.36	18.85	19.55	20.60	21.39	22.38	341.2	19.8
346.9		16.01	16.62	17.53	18.83	19.81	20.97	346.9	16.4
350.7		12.83	13.82	15.12	16.75	17.93	19.37		
354.4		8.36	10.19	12.22	14.46	15.99	17.66	352.5	10.7
358.1		3.68	6.03	8.83	11.95	13.80	15.77		
361.8		1.78	3.41	5.98	9.41	11.61	13.85		
365.4			2.13	4.13	7.30	9.56	12.06		
369.1			1.51	2.97	5.58	7.72	10.25		
372.8			1.15	2.29	4.43	6.35	8.75		
376.5			0.91	1.82	3.60	5.24	7.39		
380.1			0.75	1.49	2.97	4.38	6.33		
387.5				1.11	2.18	3.25	4.80		
394.8					1.71	2.54	3.79		
405.7				0.64		1.88	2.83		

149 (23)

153I (20)

$H$	$B_n$	$\mu_n$	$H$	$B^*$	$I$	$\mu$
0.25	100	400	150	6 400	0.0	11.2
0.5	230	460	100	6 220	76.8	11.3
0.75	480	530	50	5 930	115	11.0
1.0	650	650	25	5 580	144	10.9
1.5	1 350	900	5	4 680	172	10.5
2.5	2 800	1 120	2.5	4 360	216	9.84
5	4 330	865	+ 1	3 900	249	9.01
10	4 940	495	0	3 340	252	8.81
20	5 400	270	- 0.5	2 800	273	8.42
50	5 850	117	- 0.75	2 460	285	7.90
100	6 200	62	- 1.0	2 000	298	7.43
150	6 400	43	- 1.5	+ 550	314	6.74
300	6 700	22	- 2.5	-2 500	317	6.78
500	6 910	14	- 5	-4 320	329	6.17
1 000	7 370	7.4	- 10	-4 940		
2 000	8 400	4.2	- 20	-5 400		
3 000	9 380	3.1	- 50	-5 850		
4 000	10 400	2.6	-100	-6 200		
			-150	-6 400		

\* Cyclic:  $H_s = 1.62$ ,  $I_s = 509$ ,  $\mu_{max} = 1120$ .



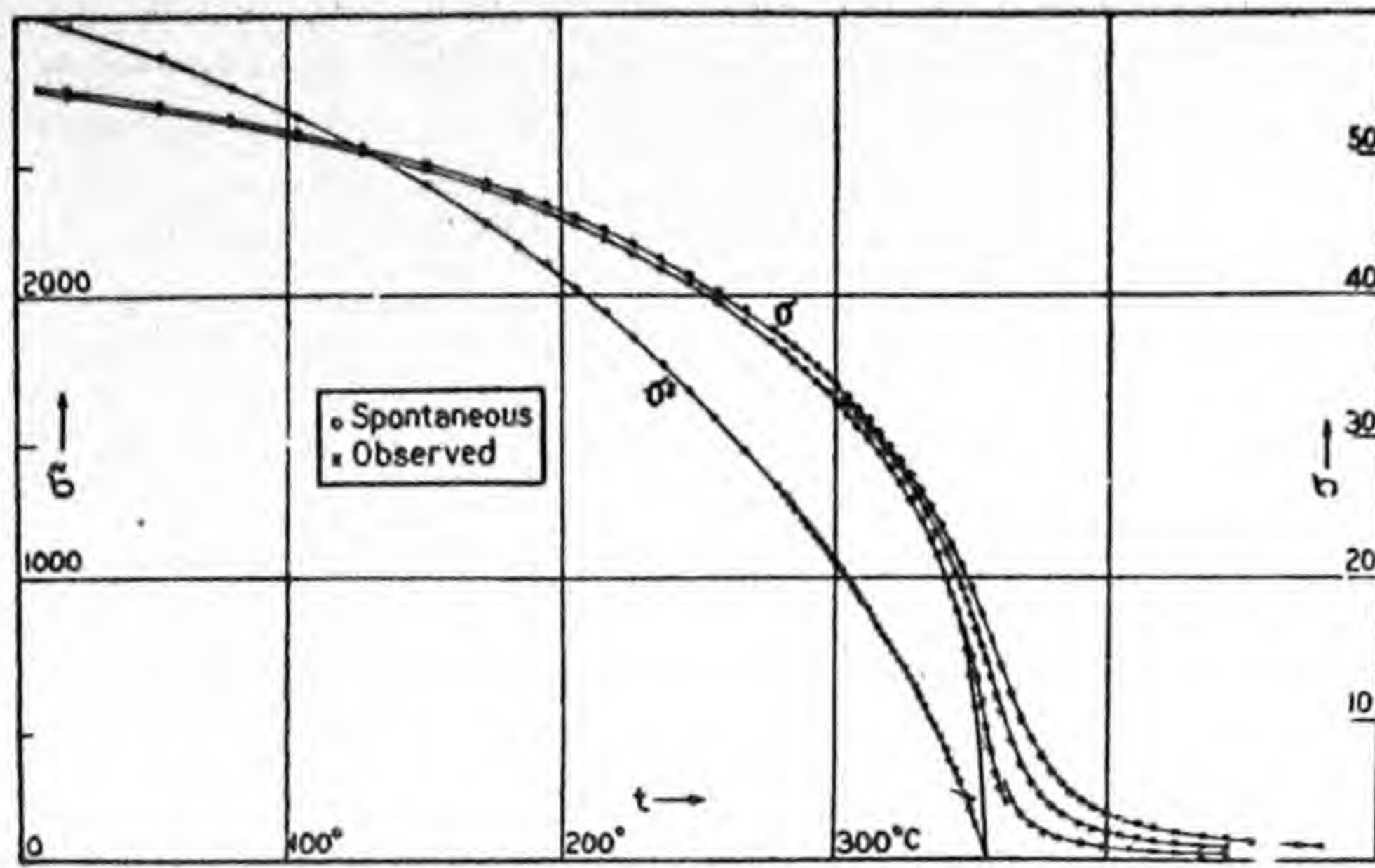


FIG. 39.—Nickel: Magnetization at various temperatures (81).  
Pure Ni (147) from Merck.

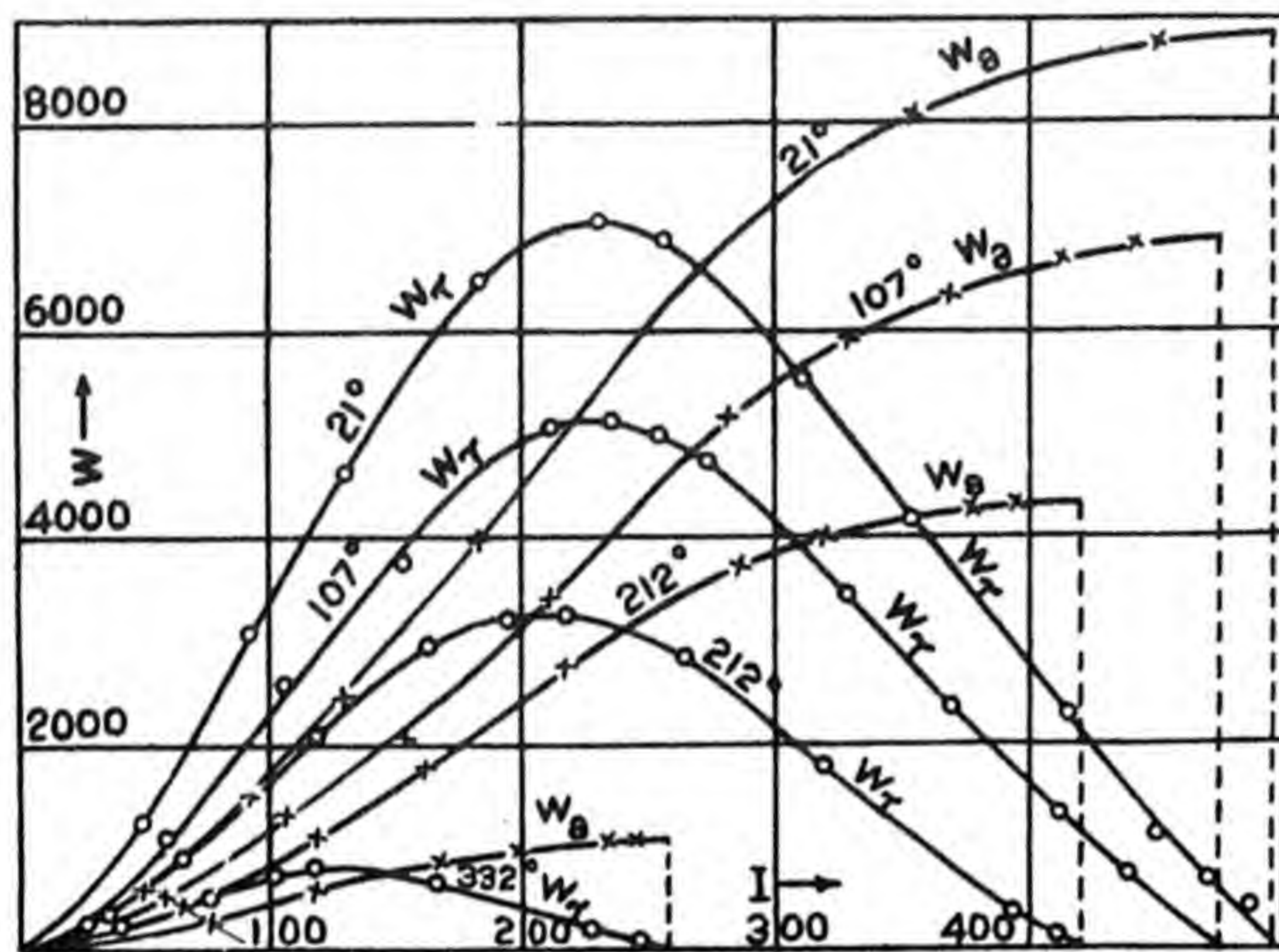


FIG. 40.—Nickel: Alternating ( $W_a$ ) and rotating ( $W_r$ ) hysteric loss (48).

Key number 153, Table 1. Centigrade temperatures.

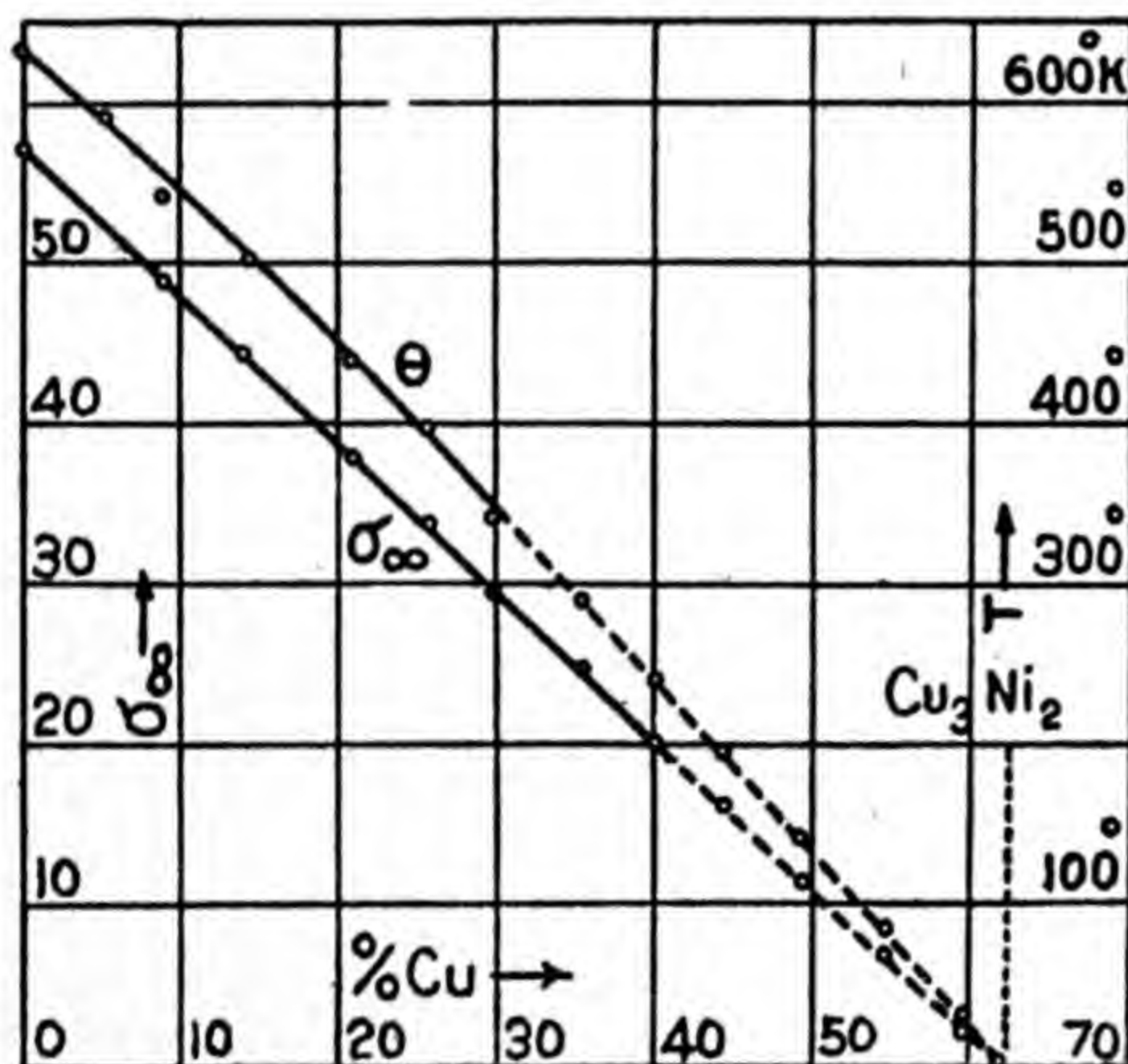


FIG. 42.—Nickel-copper (Ni-Cu) alloys: Magnetization at saturation, and Curie point (1).

Material same as in Table 20.  $T$  = absolute centigrade temperature;  $\sigma_\infty$  = value at  $T = 0$ , corrected for dilatation;  $\theta$  is for  $H = 0$ .

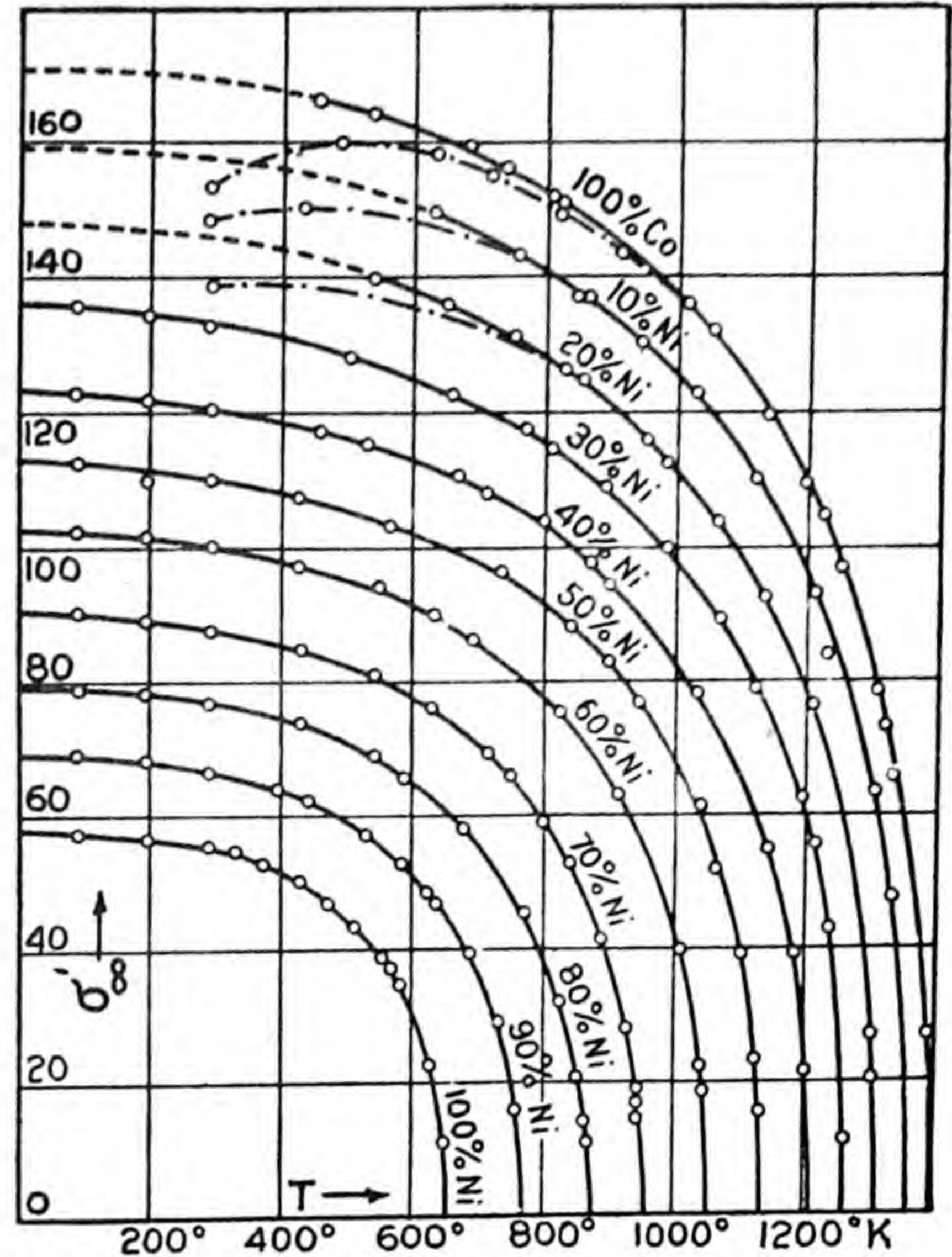


FIG. 41.—Nickel-cobalt (Ni-Co) alloys: Magnetization at saturation (7).

Material same as in Table 20.  $T$  = absolute centigrade temperature; broken lines represent  $\sigma$  for  $H = 10\,000$ .

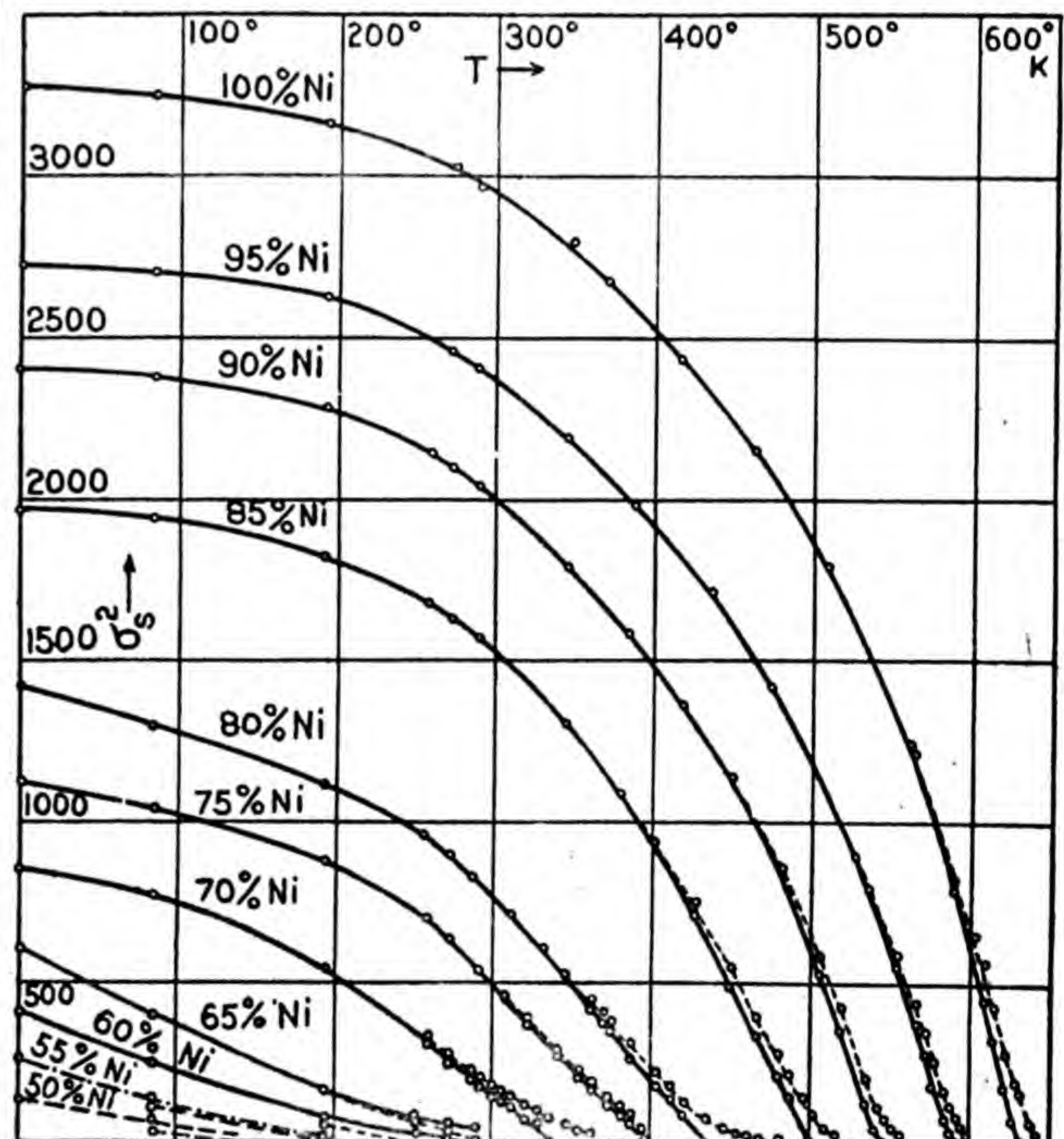


FIG. 43.—Nickel-copper (Ni-Cu) alloys: Spontaneous magnetization (1).

Material same as in Table 20.  $T$  = absolute centigrade temperature. Broken lines represent observations at  $H = 10\,000$ .



TABLE 19.—(Continued)  
153/III<sub>a</sub> (48); see also Fig. 40

H	I	W <sub>r</sub>	W <sub>a</sub>	H	I	W <sub>r</sub>	W <sub>a</sub>	H	I	W <sub>r</sub>	W <sub>a</sub>
21°C				109°C				212°C			
21	49	1 240	590	12	35	360	63	11	28	280	120
37	91	3 090	1 530	21	58	1 110	500	21	65	891	430
49	129	4 600	2 450	37	105	2 570	1 320	37	118	2 090	1 100
68	183	6 460	3 950	49	153	3 760	2 100	49	161	2 940	1 750
88	230	7 010		68	211	5 030	3 420	60	194	3 180	
100	255	6 820	6 200	78	234	5 100	4 230	68	217	3 260	2 730
130	310	5 510		86	254	4 980		88	263	2 800	
158	353	4 180	8 040	94	273	4 940		100	285		3 720
223	415	2 280	8 580	100	281		5 160	158	348	1 490	4 120
319	449	1 200	8 760	126	328	3 430	5 910	319	393	310	4 320
449	470	690	8 820	158	368	2 370	6 340	449	401		4 270
710	487	380	8 630	223	411	1 310	6 660				
				319	439	730	6 800				
322°C				153/III <sub>a</sub> (48)				153/I (18)			
t		W <sub>r</sub> *	W <sub>a</sub> *	W <sub>a</sub> /W <sub>r</sub>	t		H <sub>c</sub>				
12	41	230	120		18	12 200	15 500	1.27	-185	29.0	
21	76	510	280		100	9 700	12 700	1.31	-79	27.5	
27	103	710			150	8 000	10 700	1.33	+15	25.5	
32	117	800	610		200	6 310	8 400	1.33	123	21.2	
49	166	640	830		250	4 500	6 000	1.33	207	15.7	
68	195	350	940		300	2 580	3 440	1.33	286	9.19	
94	225	210			350	545	747	1.37	339	3.92	
158	233		1 070		368	0	0				
319	245	40	1 060								
449	247		1 060								
151 (49)											
t.....	191	220	250	270	305	361.2°C					
I <sub>r</sub> /I <sub>c</sub> .....	86.2	81.5	75.0	71.0	58.7	0%					

\* Maximum loss: Mean of values obtained when heating and when cooling.

### Alloys of Nickel

TABLE 20.—NICKEL ALLOYS

Co, Cobalt alloys of Ni (7). Ni and pure Co were fused in electric resistance furnace, in magnesia crucible, current of N. The Ni used contained 98.1% Ni, 1.9% Co, 0.05% Fe. Alloys for which Ni ≤ 20% are too hard magnetically to become saturated, at low temperatures, at  $H = 10\,000$ .  $H = 10\,000$  gauss;  $t = 19^\circ\text{C}$ ;  $\theta$  = Curie point (centigrade) for  $H = 0$ ; see also Fig. 41.

Co	d	$\sigma$	$\theta$	Co	d	$\sigma$	$\theta$
0	8.79	55.2	382	60.4	8.72	120.3	934
9.8	8.80	66.8	497	69.8	8.77	132.6	988
18.6	8.87	77.1	601	79.5	8.75	138.7	1037
30.4	8.72	87.7	685	89.3	8.87	148.5	1085
40(?)	8.89	100.0	780	100.0	8.92	153.6	1121
49.3	8.79	110.0	860				

Cu, Copper alloys of Ni (1). In N, pure Cu was fused with nickel containing 99.89% Ni, 0.004% Cu, 0.053% Fe, 0.043% C, 0.008% SiO<sub>2</sub>, traces of S. In table,  $\sigma_{\infty}$  has been corrected for dilatation, and refers to absolute zero.  $\theta$  corresponds to  $H = 0$ ; it is temperature at which spontaneous magnetization = 0; see also Figs. 42, 43.

Cu, %	d	$\sigma_{\infty}$	$\theta$ , °C	Cu, %	d	$\sigma_{\infty}$	$\theta$ , °C
0	8.790	57.2	358	20.5	8.95	37.7	164
5.3	8.787	52.2	318	25.6	8.96	33.9	126
9.1	8.86	49.0	272	29.7	8.99	29.2	67
14.1	8.94	44.4	229	35.5	8.91	24.5	+16

TABLE 20.—(Continued)

Cu, %	d	$\sigma_{\infty}$	$\theta$ , °C	Cu, %	d	$\sigma_{\infty}$	$\theta$ , °C
40.0	8.90	20.0	-33*	54.1	8.93	6.8*	-188*
44.3	8.85	16.2*	-79*	59.4	8.93	2.0*	-245*
49.2	8.96	11.4*	-133*	61.8†		0*	-273*

\* Extrapolated value. † Corresponds to Cu<sub>3</sub>Ni<sub>2</sub>.

Fe, For ferronickels, nickel steel, see Table 17 (Ni).

Mn, Nickel manganese alloys (21). The metals, protected from all contact with C, were fused under a layer of fused BaCl<sub>2</sub>. Annealed at 900°C. Unforged castings and specimens quenched at 900°C are, in general, less magnetic than those annealed.

H =	5	10	15	20	40	60	80	100	150	200
% Mn	I <sub>n</sub> , Intensity of magnetization; 16°C									
5	20	48	77	97	158	195	224	248	292	316
10	30	75	109	130	212	258	287	308	344	368
15	68	115	148	167	214	240	256	268	288	304
20	20	32	41	47	64	76	85	91	102	110
25	6	12	18	28	58	80	96	109	131	147
30	2	4	7	11	30	48	67	81	112	135
% Mn	I <sub>n</sub> , Intensity of magnetization; -190°C									
5	16	40	66	89	155	203	236	264	317	350
10	26	60	97	129	224	280	318	353	404	434
15	42	100	146	176	262	316	344	368	410	438
20	30	70	99	123	181	216	236	250	276	296
25	10	24	38	51	94	130	156	180	217	247
30	3	6	10	14	35	54	72	89	123	152



## Manganese Alloys and Compounds

TABLE 21.—FERROMAGNETIC MANGANESE ALLOYS AND COMPOUNDS

For composition of alloys denoted by key numbers, see Table 1

**As**, Two ferromagnetic alloys (28, 70);  $\text{MnAs}$ ,  $\theta = 40$  to  $45^\circ\text{C}$ , and  $\text{Mn}_2\text{As}$ .**B**, One ferromagnetic alloy (6);  $\text{MnB}$ ,  $\theta = 260^\circ\text{C}$ ;  $H_c = 30.9$ .

$H$ .....	90.4	181	271	362	542	786
$I_n$ .....	32.5	54.6	70.7	81.5	110.1	146.1

**Bi**, One ferromagnetic alloy (28, 70);  $\text{MnBi}$ ,  $\theta = 360$  to  $380^\circ\text{C}$ .**C**, One ferromagnetic alloy (28, 70);  $\text{Mn}_3\text{C}$ , no data.**Cu**, Cupromanganese is not ferromagnetic, but certain of the three-component alloys containing Al or Sn are.

1. Copper, Manganese, Aluminium (Heusler) alloys (29) contain from 5 to 25% Al,  $\text{Mn} > 7\%$ ; alloys containing over 30% **Mn** have not been studied. Of these alloys those of the composition  $\chi\text{AlCu}_3 + (1 - \chi)\text{AlMn}_3$  are the most magnetic (they contain about 13% Al) and, for  $H = 150$ , the maximum value of  $I$  (about 430) corresponds to  $\chi = 0.6684$ , or 12.89% Al, 26.12% Mn, 60.98% Cu (see Fig. 45). It is understood that each alloy is given the thermal treatment which is most appropriate to itself, see Figs. 44, 45, 46. 156 is a typical Heusler alloy.

 $156t_v = 600^\circ\text{C}$ , drawn at  $209^\circ\text{C}$  for  $\tau_d$  hr

$H$	2.5	5	10	25	50	100	200	500	700	1000
$\tau_d$	$I_n$ , Normal intensity of magnetization (67); see Fig. 46									
0	0.04	0.09	0.18	0.45	0.90	1.75	3.11	6.02	7.60	9.73
1	1.34	2.70	5.07	8.78	12	15.9	20.6	26.2	28.0	30.6
2	2.45	5.01	9.37	16.5	22.6	29.0	36.0	44.1	47.7	53.2
3	4.00	8.52	16.2	27.3	35.7	44.1	52.1	61.6	65.5	69.4
4	4.71	11.1	23.1	38.1	48.1	57.3	65.9	75.6	78.6	81.6
5	4.37	11.3	31.1	50.2	61.0	70.8	79.5	88.8	92.1	94.5
6	3.11	9.40	31.1	50.5	62.0	72.5	81.5	91.6	94.7	97.2
7	3.18	9.71	29.0	47.0	59.0	69.8	79.5	90.2	93.4	96.7
8	3.00	7.61	24.7	65.7	70.4	92.1	102.2	113.8	116.4	119.1
9	3.25	8.30	26.5	52.6	64.4	75.5	85.6	96.7	99.7	103.1
10	2.88	7.31	23.5	48.4	61.5	72.7	83.3	95.0	98.6	102.0
12½	2.10	5.65	21.1	49.3	63.5	75.7	87.6	100.0	103.7	107.5
15	2.05	5.43	16.9	46.2	61.6	75.1	87.6	100.9	104.9	109.4
20	1.80	4.05	10.7	37.3	55.0	71.5	86.7	103.5	108.3	112.7
25	1.15	2.70	6.72	27.3	52.5	68.2	85.2	107.2	113.1	119.1
35	0.88	1.96	4.23	14.9	32.6	53.9	79.0	110.1	119.7	127.3
50	0.61	1.26	2.65	7.88	21.0	44.5	75.3	116.6	128.4	137.8
75	0.42	0.85	1.75	4.55	9.46	20.1	43.4	100.4	116.9	130.1
2100	0.38	0.76	1.52	3.82	7.73	17.0	41.6	118.2	139.0	156.3

$H$	155 (3)		159 (3)		Cyclic $H$	155 (3)	159 (3)	155	159
	$B_n$	$\mu_n$	$B_n$	$\mu_n$		$B$	$B$	Malleable	Not malleable
2.5	120	48	300	120	150	2250	4250	Cu, 75.6%	61.5%
5	400	80	800	160	100	1980	4110	Mn, 14.25	23.5
7.5	580	77	1600	210	50	1560	3830	Al, 10.15	15.0
10	720	72	2320	230	25	1220	3550	Pb	0.1
20	1070	54	3250	160	+ 5	740	2900		
50	1540	31	3800	76	0	480	2550	$B_r$ , 480	2550
75	1780	24	3980	53	- 0.5	440	2490	$H_c$ , 3.75	7.3
100	1970	20	4110	41	- 1.0	410	2420	$\mu_n(\text{max.}) = 80$	236
150	2250	15	4250	28	- 1.5	370	2350	$4\pi I_{\text{obs.}} = 2790$	
300	2800	9.3			- 2.5	+ 250	2190	$\rho_{20} = 40.90$	
500	3120	6.2			- 5	- 240	+1480		
1000	3670	3.7			- 10	- 670	-1780		
2000	4710	2.4			- 20	-1040	-3210		
3000	5750	1.9			- 50	-1540	-3800		
4000	6780	1.7			- 75	-1780	-3980		
5000	7790	1.6			-100	-1970	-4110		
6000	8790	1.5			-150	-2250	-4250		



TABLE 21.—(Continued)

2. Copper, manganese, tin alloys (60). A 98.5% Mn, containing in decreasing amounts Si, Fe, and Al, was alloyed with very pure Cu and Sn; the alloys were drawn for a short time at a temperature below 200°C. There are 2 series of ferromagnetic alloys, separated by the alloy of 30% Sn.

$H =$		20	50	100	200	300	$I_r$	$H_c$	$H =$		20	50	100	200	300	$I_r$	$H_c$
Key	$t$	$I_n$							Key	$I_n$							
$\theta = 275^\circ\text{C}$	162	-190	21	42	67	93	108	31	27	163	30	62	96	127	144	26	12
		+ 15	18	36	55	72	80	21	22		28	55	77	96	105	16	10
		75	15	30	46	60	67	18	21		24	46	63	76	84	14	9
		125	11	26	37	46	50	13	20	$\theta = 270^\circ\text{C}$	20	37	48	58	61	10	8
		180	8	19	26	34	36	8	18		11	19	27	31	33	5	7
		230	2	3	4	5	5	1	9		4	7	10	12	13	2	5
$\theta = 255^\circ\text{C}$	164	-190	27	59	102	162	195	23	16	166	22	54	96	160	209	11	10
		+ 15	24	52	82	117	129	18	14		22	54	96	160	209	11	9
		75	18	36	59	82	89	13	13		22	52	92	153	201	11	9
		125	12	23	35	49	54	9	12	$\theta = 225^\circ\text{C}$	21	50	88	142	184	10	8
		180	6	13	19	27	29	5	10		21	47	83	130	160	8	7
		230	2	4	5	9	11	1	4		0	0	0	0	0	0	0
165	15	(?)	(?)	(?)	0.8	1.2	(?)	(?)	167	(?)	0.5	1.0	2.0	3.0	0.5	40*	

\* Approximate.

Fe, see Table 17 (Mn).

H, Mn fused in H is ferromagnetic (40); perhaps hydride is formed. At  $H = 12\,000$ ,  $\sigma = 2.2$ ;  $H_c = 670$ ;  $d = 7.24$ ; see Fig. 47.

N,  $Mn_3N_2$ ,  $Mn_5N_2$ ,  $Mn_7N_2$  are ferromagnetic (28, 70); no data.

Ni, see Table 20 (Mn).

P,  $MnP$ ,  $Mn_3P_2$ ,  $Mn_5P_2$  are ferromagnetic (28, 70).

$MnP$ ,  $\theta = 18$  to  $26^\circ C$

H.....	85.8	172	343	515	746
I <sub>n</sub> .....	9.2	15.6	22.8	32.8	38.8

S,  $MnS$  is ferromagnetic (28, 70); no data.

Sb, Definite compounds of composition  $MnSb$  (68.9% Sb),  $Mn_3Sb_2$  (59.8% Sb), and  $Mn_2Sb$  (52.6% Sb) are formed. For alloys fused in H and cast in red-hot iron molds (32) found:

% Sb.....	20	40	45	52.2	59.3	68.6	72	90	95	98
H.....	5259	5244	5211	5353	5274	5238	5401	5421	5414	5276
I <sub>n</sub> .....	62	119	159	176	245	345	317	158	67	37

For  $Mn_3Sb_2$ ,  $\theta = 315^\circ C$ ; for  $Mn_2Sb$ ,  $\theta = 275^\circ C$  (32):

$MnSb$  (28, 70)  $H_c = 8.2$ ;  $\theta = 320$  to  $330^\circ C$

H.....	88.9	178	267	356	533	773
I.....	82	142	188	229	294	361

$Mn_2Sb$  (28, 70)  $H_c = 33.4$

H.....	70.4	141	211	282	422	612
I.....	20.4	31.4	43.5	48.5	63.3	74.6

Se, Si, Te,  $MnSe$ ,  $MnSi$ ,  $MnTe$  are ferromagnetic (28, 70); no data.

#### Transformation Temperatures

TABLE 22.—TRANSFORMATION POINTS

The Curie point ( $\theta$ ) is the temperature at which the spontaneous magnetization becomes zero and the material ceases to be ferromagnetic. In intense fields, the change from ferromagnetic to paramagnetic occurs gradually and the intersection of the steeply inclined portion of the ( $I$ ,  $t$ ), ( $\sigma$ ,  $t$ ), ( $I^2$ ,  $t$ ), or ( $\sigma^2$ ,  $t$ ) curve with the axis of  $t$  is generally taken as  $\theta$ ; this intersection depends upon the intensity of the field; see Fig. 39. The following data are arranged in the order Fe, Ni, Co; each is followed by its alloys and compounds, arranged alphabetically by symbol of second constituent. For composition of alloys denoted by key numbers, see Table 1.

Fe, Iron. Transformation  $\alpha$  to  $\beta$ , Osmond's  $A_2$  point, corresponds to  $\theta$ ; transformation  $\beta$  to  $\gamma$  corresponds to Osmond's  $A_1$  point, his  $A_4$  point corresponds to transformation  $\gamma$  to  $\delta$ . In following table + [−] placed after a symbol denotes that the value corresponds to increasing [decreasing] temperature.  $\theta = \theta_0 + 0.14\sqrt{H}$  (58).

Key	$\theta$ ; $A_2$	$A_2+$	$A_2-$	$A_4+$	$A_4-$	H	Method	Lit.
2		910	905	1 407	1 410		Magnetic	(69)
3	774	920	900		1 407	10 000	Magnetic	(53)
4		920	920	1 396			Magnetic	(76)
9	784					0	Calorimetric	(85)
9	769	917				0.96	Magnetic	(58)
11		903	903	1 390	1 390		Magnetic	(36)
12		916	890				Magnetic	(35)
12		910	894			0	Thermometric	(35)
27	770				1 420	0	Thermometric	(61)



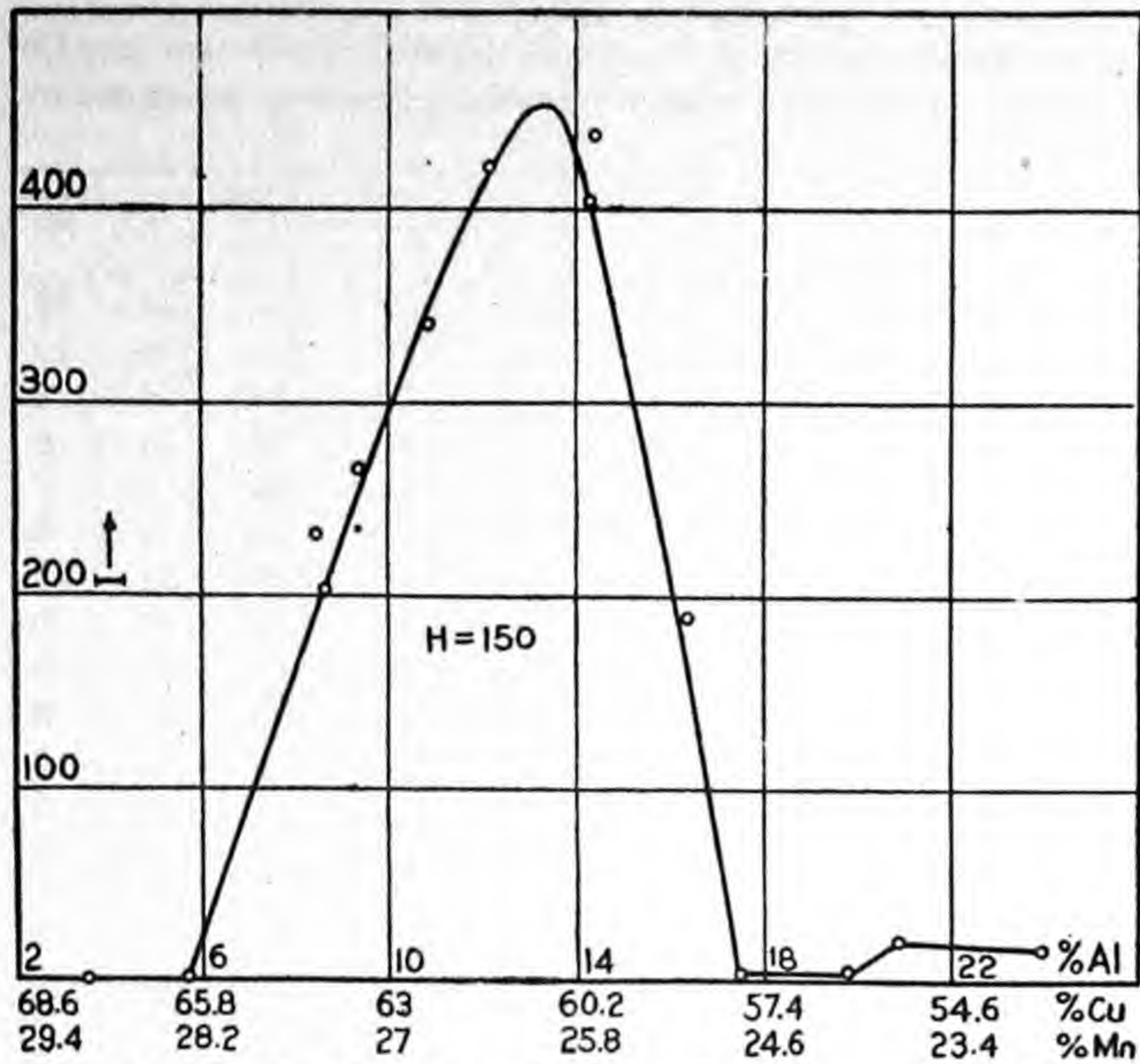


FIG. 44.—Heusler alloy: Variation of magnetization with Al content (29).

Alloys were made by adding Al to a cupromanganese containing 30% Mn.

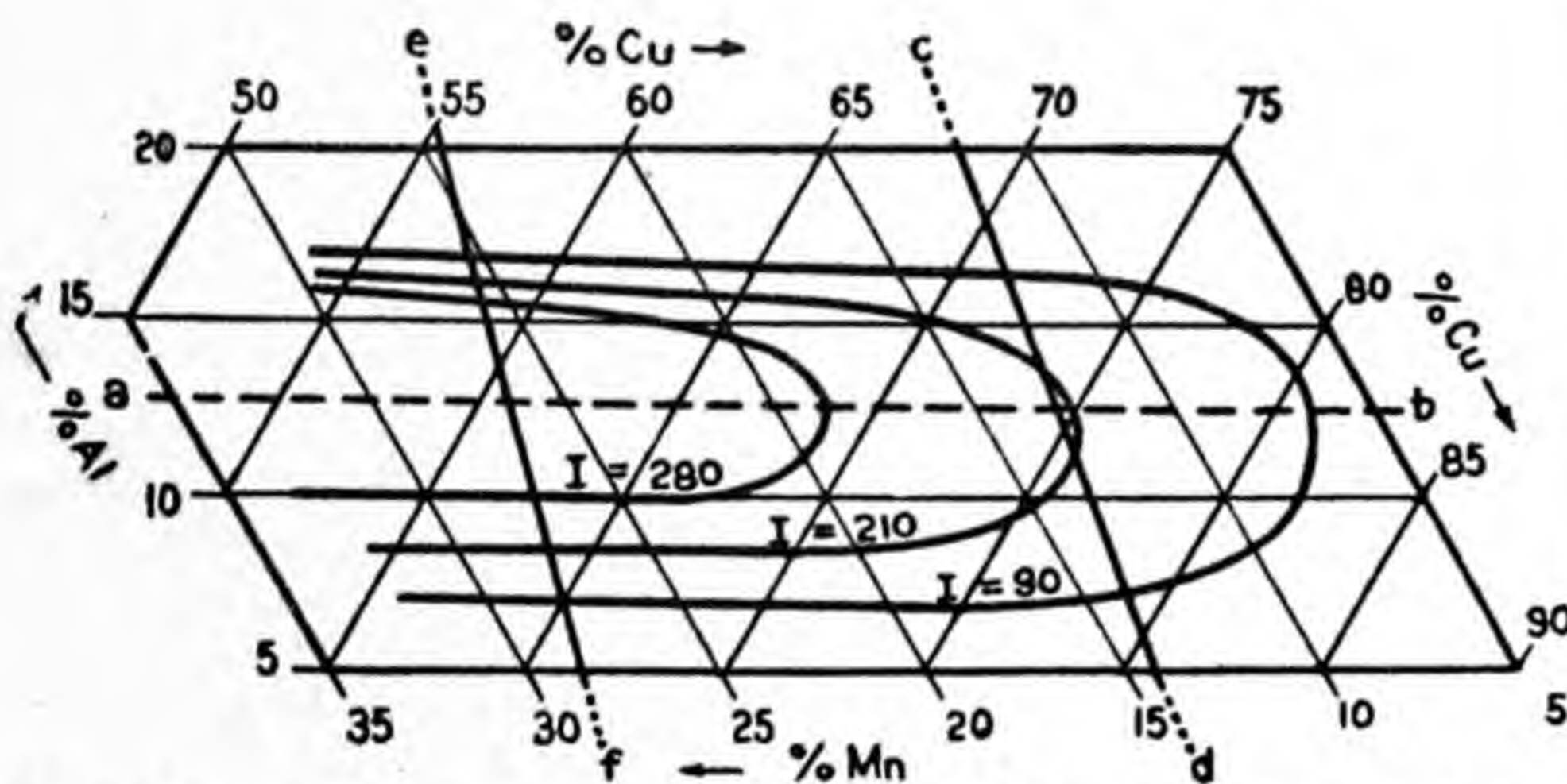


FIG. 45.—Aluminum-manganese-copper (Al-Mn-Cu) alloys: Variation of magnetization with composition (29).

$H = 150$ . Line  $ab$  joins the points  $AlCu_3$  and  $AlMn_3$ . Alloys formed by adding Al to cupromanganese containing 30 and 15% Mn, respectively, lie on the lines  $ef$  and  $cd$ . Maximum value of  $I$ , about 430, is at intersection of  $ab$  and  $ef$ . Each alloy was given a heat treatment which was appropriate to itself. Data are from Table 21.

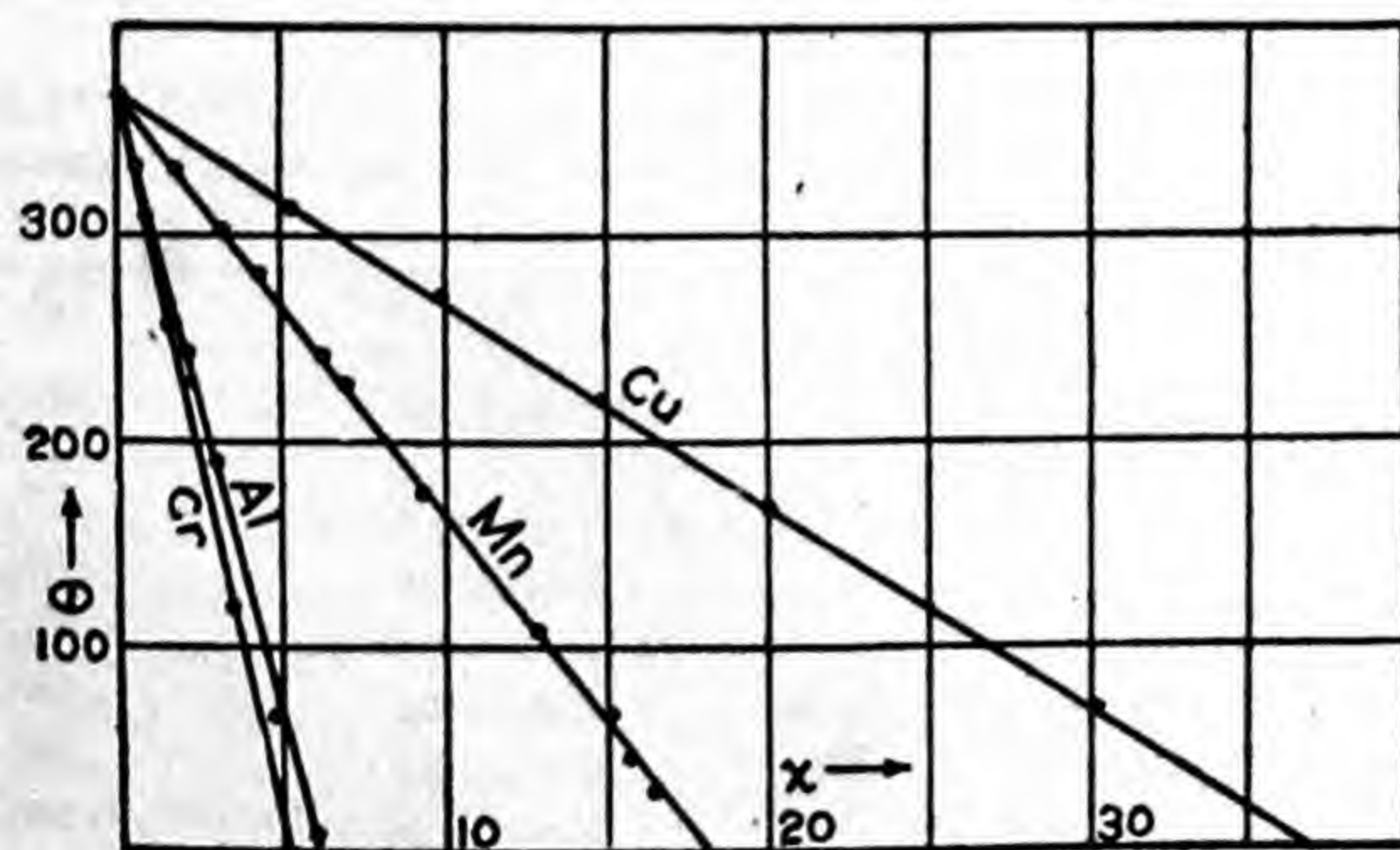


FIG. 48.—Binary alloys of nickel: Curie points (13).  
 $x$  = % of the constituent named on the curve.

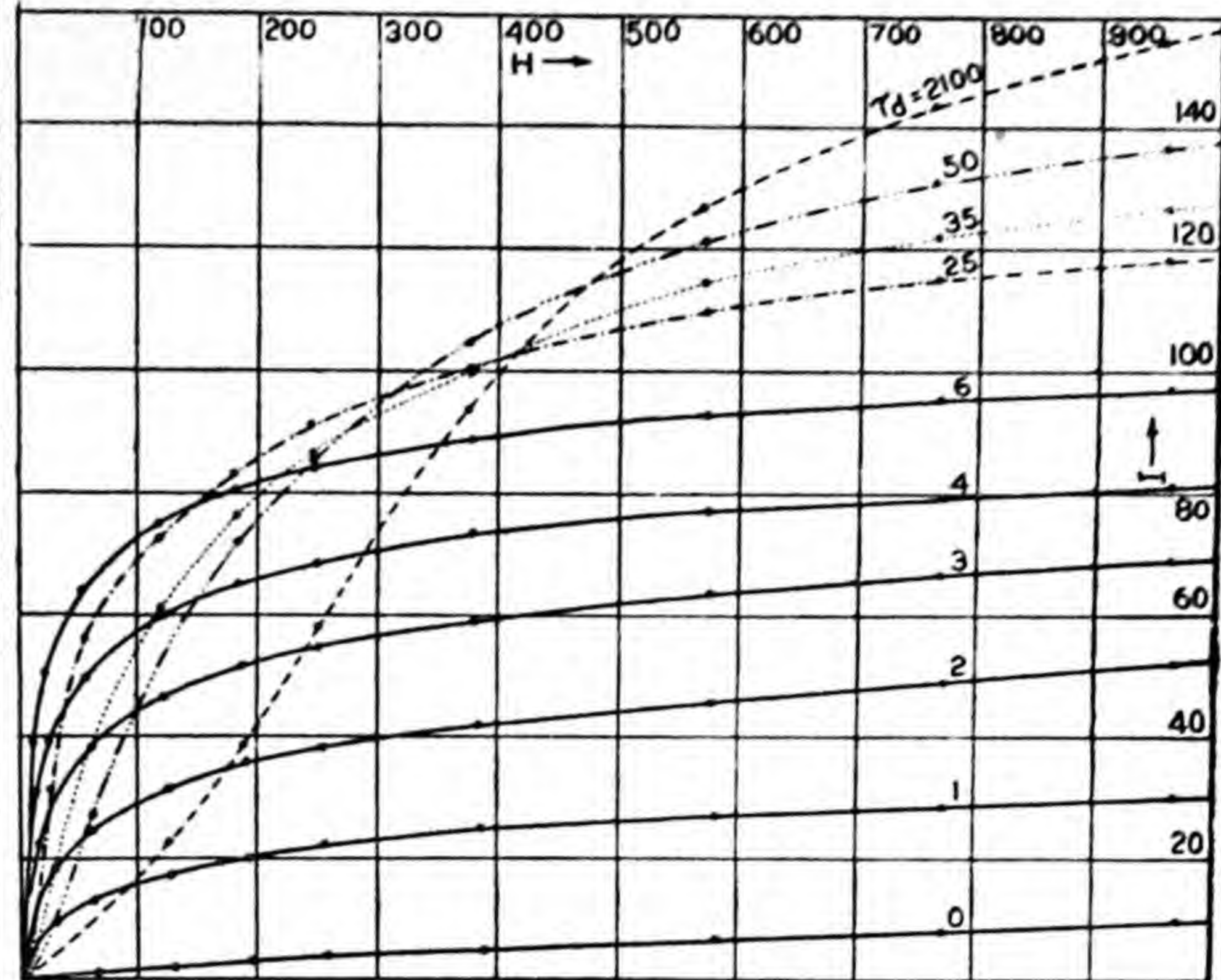


FIG. 46.—Heusler alloy (156): Variation of magnetization with heat treatment (67).

Quenched at 600°C and drawn to 209°C for the number of hours indicated on the curves.

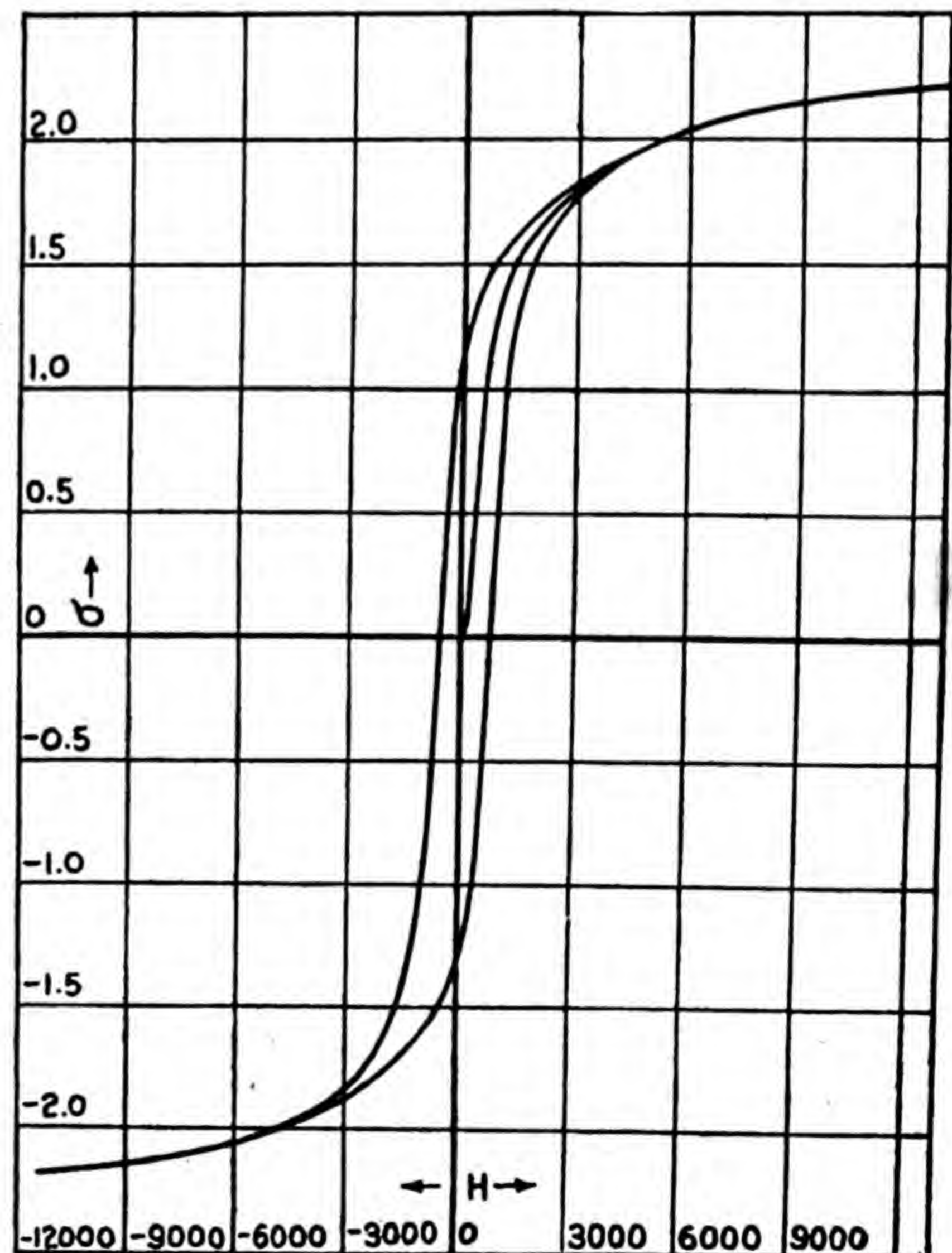


FIG. 47.—Manganese: Magnetization (46).  
Mn fused in H; possibly a hydride.  $H_0 = 670$ ; v. Table 21.



C, Fe, Fe<sub>3</sub>C, Cementite (35),  $\theta = 215^\circ\text{C}$ .

Co, Fe, Iron cobalt alloys; see Table 17 (Co).

Cu, Fe, Iron copper alloys; see Table 17 (Cu).

N, Fe, Fe<sub>4</sub>N,  $\theta = 390^\circ\text{C}$ ; Fe<sub>2</sub>N is not ferromagnetic at room temperatures (17).

Ni, Fe, Iron nickel alloys; see Table 17 (Ni).

O, Fe, Magnetite (Fe<sub>3</sub>O<sub>4</sub>).  $\theta = \theta_0 + 0.08\sqrt{H}$  (see (58)). By magnetic methods (58, 74)  $\theta = 582$  to  $586^\circ$ ; by calorimetric methods (85)  $\theta = 585$  to  $593^\circ$ .

Compounds resembling magnetite (8);

FeO.Fe <sub>2</sub> O <sub>3</sub>	CoO.Fe <sub>2</sub> O <sub>3</sub>	CuO.Fe <sub>2</sub> O <sub>3</sub>	CaO.Fe <sub>2</sub> O <sub>3</sub>
$\theta = 555$	520	418	156°C

Hematite (Fe<sub>2</sub>O<sub>3</sub>) (41).  $\theta$  is about  $600^\circ\text{C}$ . (Temperature corrected on basis of measurement (41) of pyrrhotite.)

S, Fe, Pyrrhotite (FeS with excess of S). Both dilatometric (12) and magnetic (95) methods give  $\theta = 320^\circ\text{C}$ ; see also p. 413.

V, Fe, Iron vanadium alloys are ferromagnetic if  $V < 80\%$ ; approximate values, temperature increasing, are (31):  $V = 0\%$ ,  $\theta = 775^\circ$ ;  $V = 20\%$ ,  $\theta = 720^\circ$ ;  $V = 30\%$ ,  $\theta = 600^\circ\text{C}$ .

Ni, Nickel. For pure Ni (55),  $\theta = \theta_0 + 0.20\sqrt{H}$ . By magnetic measurements (1, 79), Ni fused in H (145) or in N (152),  $\theta = 357.6$  or  $358^\circ\text{C}$ , respectively, by calorimetric measurements (85), Ni (152) fused in air,  $\theta = 363^\circ\text{C}$ .

Al, Ni, Nickel aluminium alloys, see Fig. 48.

Co, Ni, Nickel cobalt alloys, see Table 20 (Co).

Cr, Ni, Nickel chromium alloys, see Fig. 48.

Cu, Ni, Nickel copper alloys, see Table 20 (Cu), and Fig. 48.

Fe, Ni, Nickel iron alloys, see Table 17 (Ni).

Mn, Ni, Nickel manganese alloys, see Fig. 48.

Sn, Ni, Nickel tin alloys (31), ferromagnetic if  $\text{Sn} < 40\%$ .

Sn.....	0	10	20	30	36%
$\theta$ .....	370	320	210	210	$210^\circ\text{C}$ (approximate)

Co, Cobalt. By magnetic methods,  $H$  small (7, 66),  $\theta = 1075$  to  $1115^\circ\text{C}$ ;  $H = 10\,000$  (53),  $\theta = 1140^\circ\text{C}$ . By thermometric methods (62),  $\theta = 1102$  to  $1112^\circ\text{C}$ .

Cr, Co, Cobalt chromium alloys (31) are ferromagnetic if  $\text{Cr} < 25\%$ .

Cr.....	0	10	15	20%
$\theta$ .....	1140	720	480	$180^\circ\text{C}$ (approximate)

Mn, Sb, Manganese antimony alloys, see Table 21 (Sb).

Mn, Cu, Al, Heusler alloys (54):

Key	Mn, %	Al, %	Cu, %	$\theta$ , °C
154	13.9	7.2	78.9	200 to 210
157	6.0	13.2	80.8	300 to 310
158	19.3	14.0	66.6	340 to 350
160	26.5	16.3	57.2	320 to 330
161	11.6	25.0	63.4	5 to 10

For other Mn alloys and compounds, see Table 21.

### Magnetization of Ferromagnetic Crystals

Fe, Iron. Cubic system; data (5) (Fig. 49 to 54) refer to discs,  $H$  lies in plane of disc;  $\sigma_p$  = component of  $\sigma$  parallel to  $H$ ;  $\sigma_n$  = component in plane of disc and normal to  $H$ .  $\varphi$  = azimuth of  $H$  with reference to some stated axis of the crystal. Impurities amount to 1.93%, being C = 0.06%, Si = 1.62%, Mn = 0.16%, P = 0.050%, and S = 0.040%.

In each figure (49 to 54) the values of  $H$  for the several curves are as follows:

Curve	$H$	Curve	$H$
1	17	8	798
2	44	9	1110
3	71	10	1527
4	111	11	2050
5	189	12	4090
6	389	13	6000
7	595	14	9420

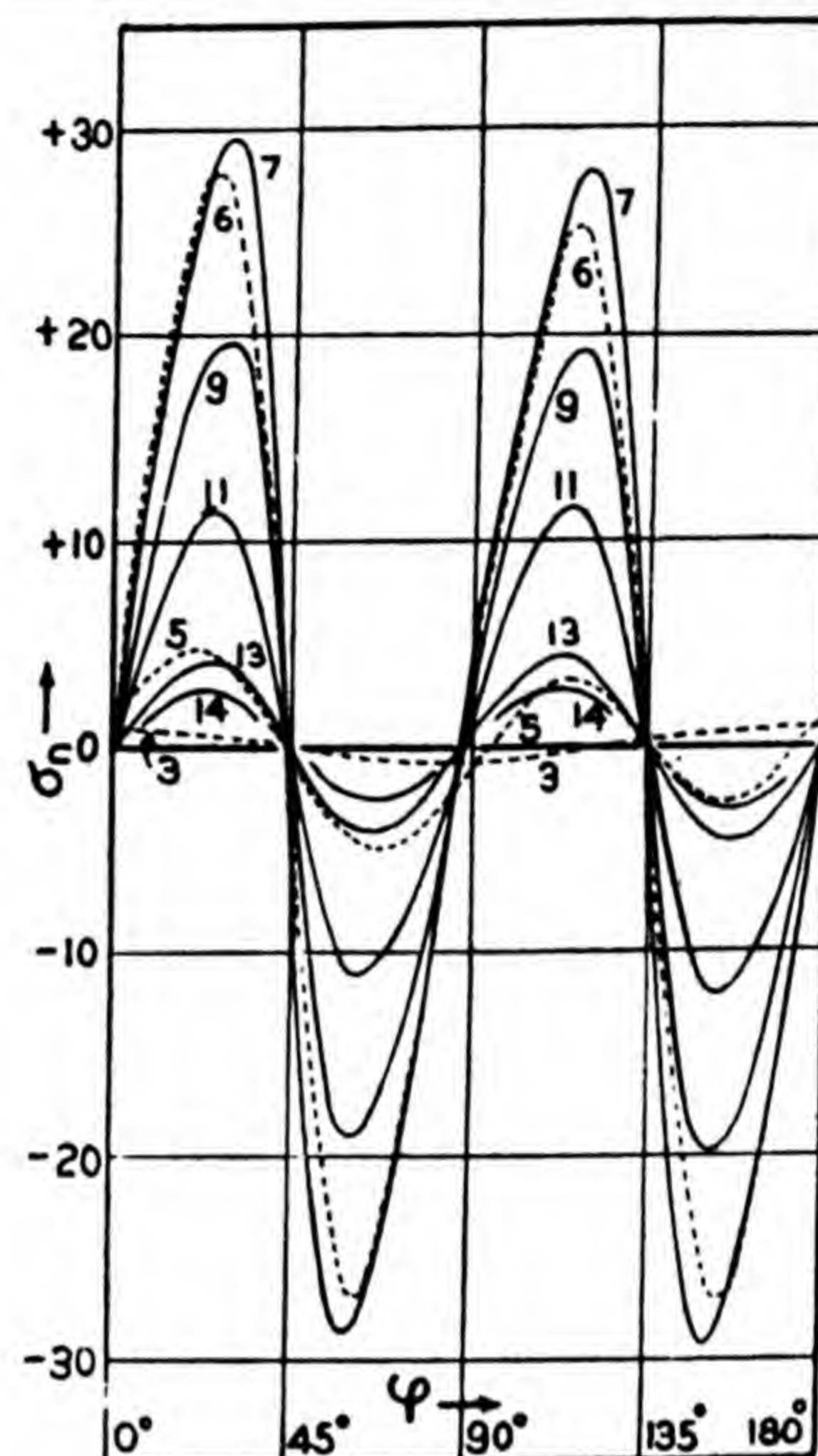


FIG. 49.—Iron crystal.

FIGS. 49, 51.—Disc was cut parallel to face of the cube; diameter = 6.90 mm, thickness = 0.090 mm; quaternary axes (edges of cube) at  $\varphi = 0^\circ, 90^\circ, 180^\circ$ ; binary axes (diagonals of faces) at  $\varphi = 45^\circ$  and  $135^\circ$ . For values of  $H$ , see preceding text.

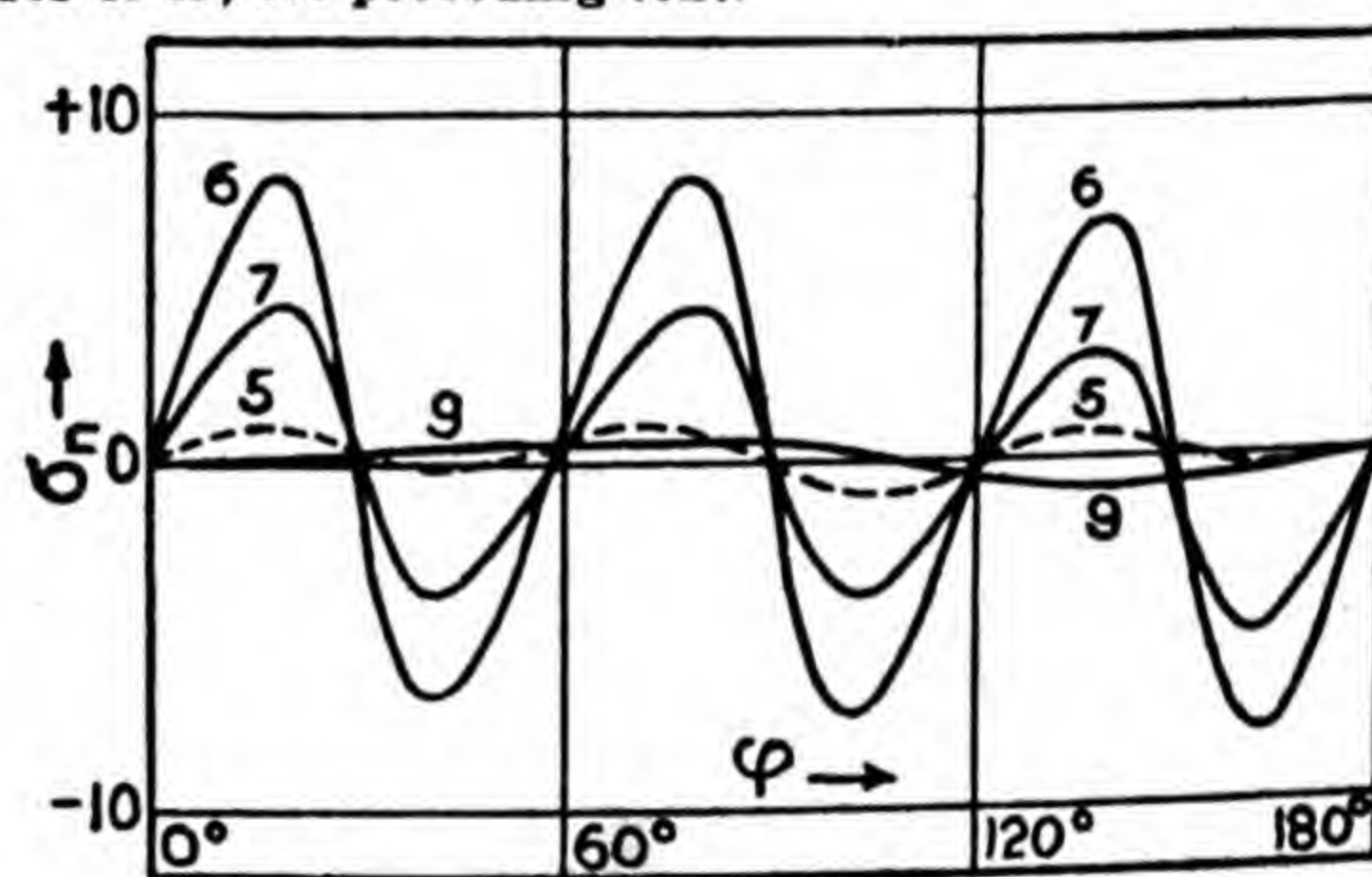


FIG. 50.—Iron crystal.

FIGS. 50, 52.—Disc was cut parallel to face of octahedron; diameter = 7.64 mm, thickness = 0.110 mm; binary axes at  $\varphi = 0^\circ, 60^\circ, 120^\circ$ , and  $180^\circ$ . For values of  $H$ , see preceding text.

Fe<sub>3</sub>O<sub>4</sub>, Magnetite. Cubic system: data for the crystal (Fig. 55, 56, 57) apply to Brozzo magnetite at room temperature; for Fig. 56, 57 test piece was a disc 20 mm diameter, 0.3 mm thick. The thermal data (Table 23) refer to a crystalline mass of artificial magnetite, crystals oriented indifferently in all directions; are relative to Kopp's value (39) at  $19^\circ$  and in intense fields,  $\sigma = 93.3(1 - \frac{19}{H})$ ; precision about 0.05% except for observations below  $17^\circ$ , those are less reliable on account of doubtful purity. For  $t < 500^\circ$ ,  $\sigma$ , practically =  $\sigma_n$ ; see also Tables 3 and 4.



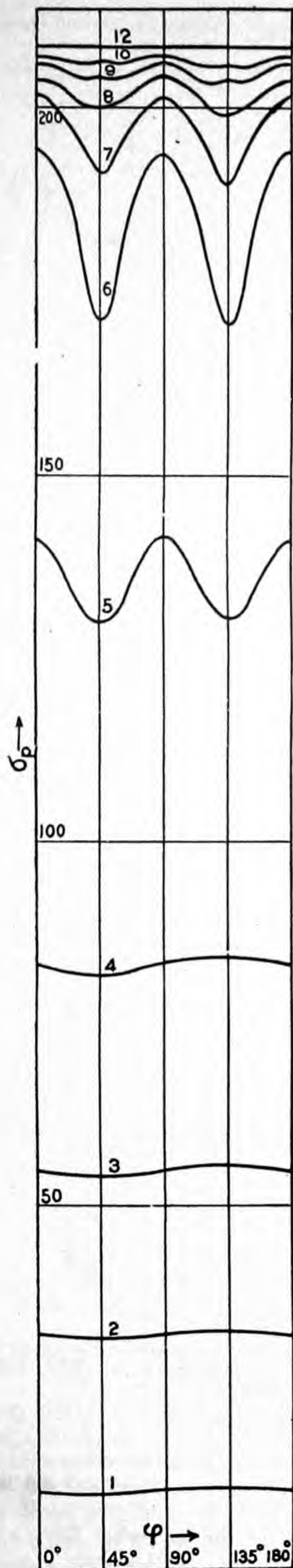


FIG. 51.—(See Fig. 49.)

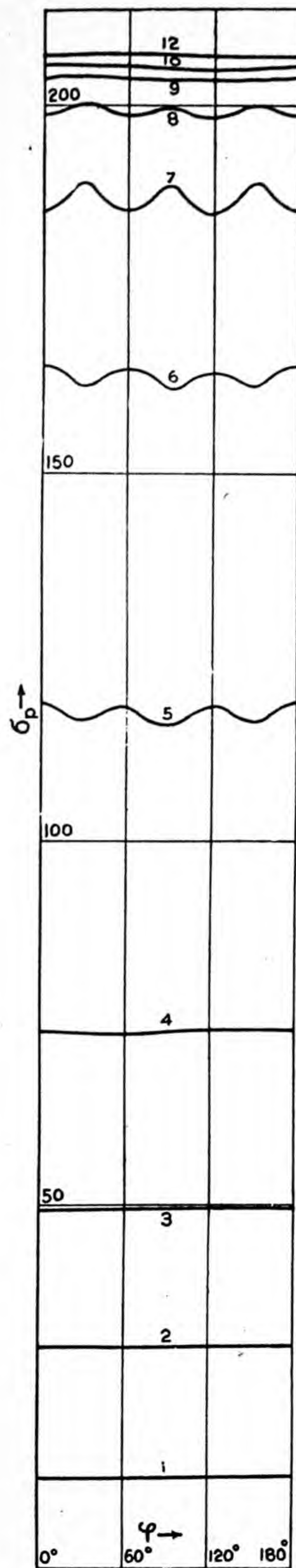


FIG. 52.—(See Fig. 50.)

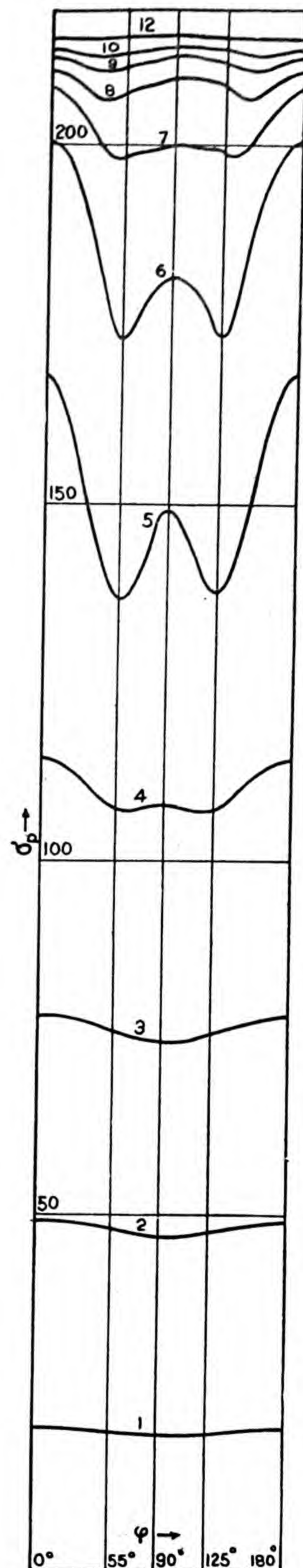


FIG. 53.—(See Fig. 54.)



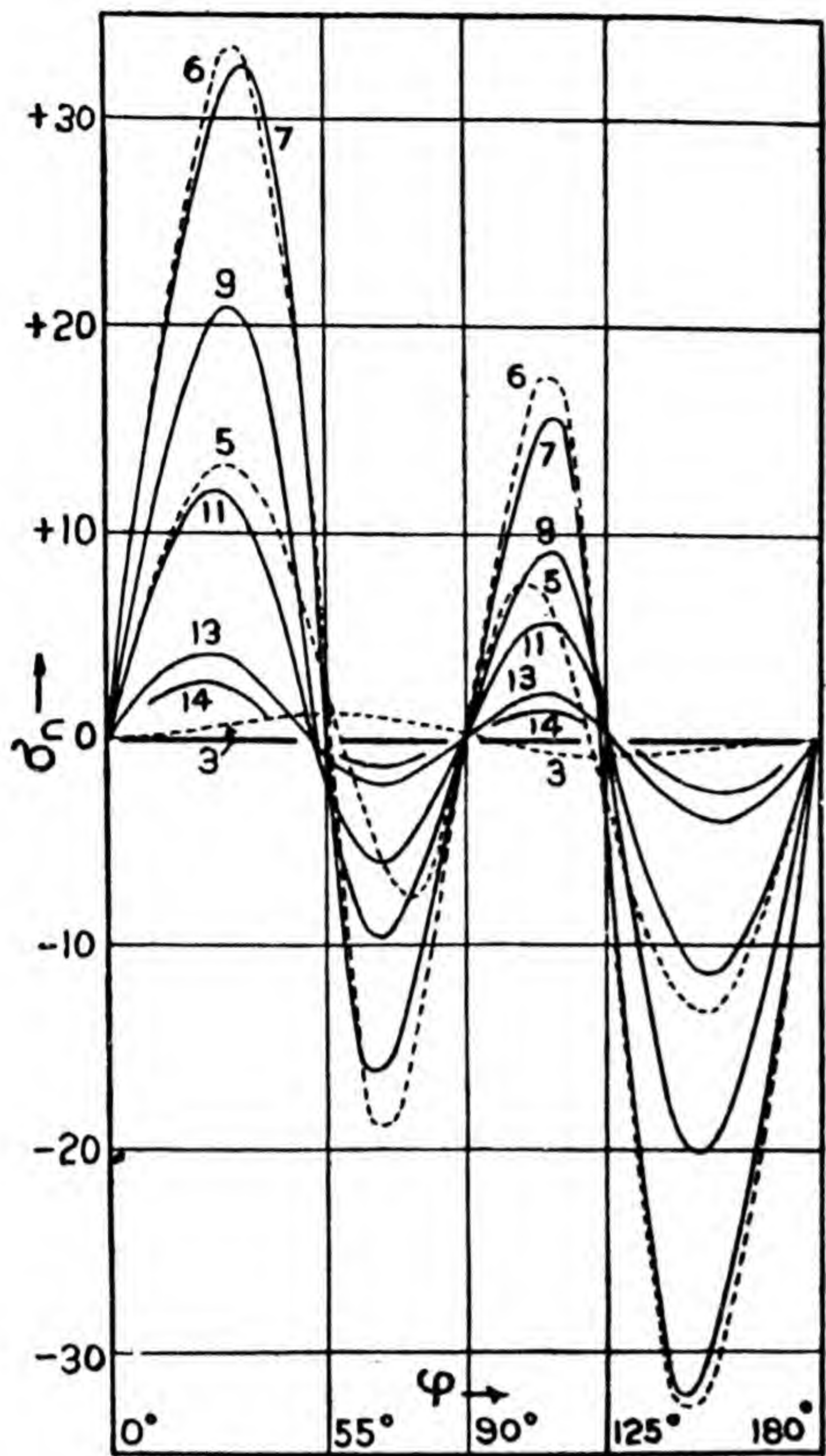


FIG. 54.—Iron crystal.

FIGS. 53, 54.—Disc was cut parallel to face of rhombohedral dodecahedron; diameter = 9.20 mm, thickness = 0.085 mm; a quaternary axis lies in the line  $\varphi = 0^\circ, 180^\circ$ , a binary axis at  $\varphi = 90^\circ$ , one ternary axis at  $\varphi = 54^\circ 44'$  and another at  $\varphi = 125^\circ 16'$ . For values of  $H$ , see p. 410.

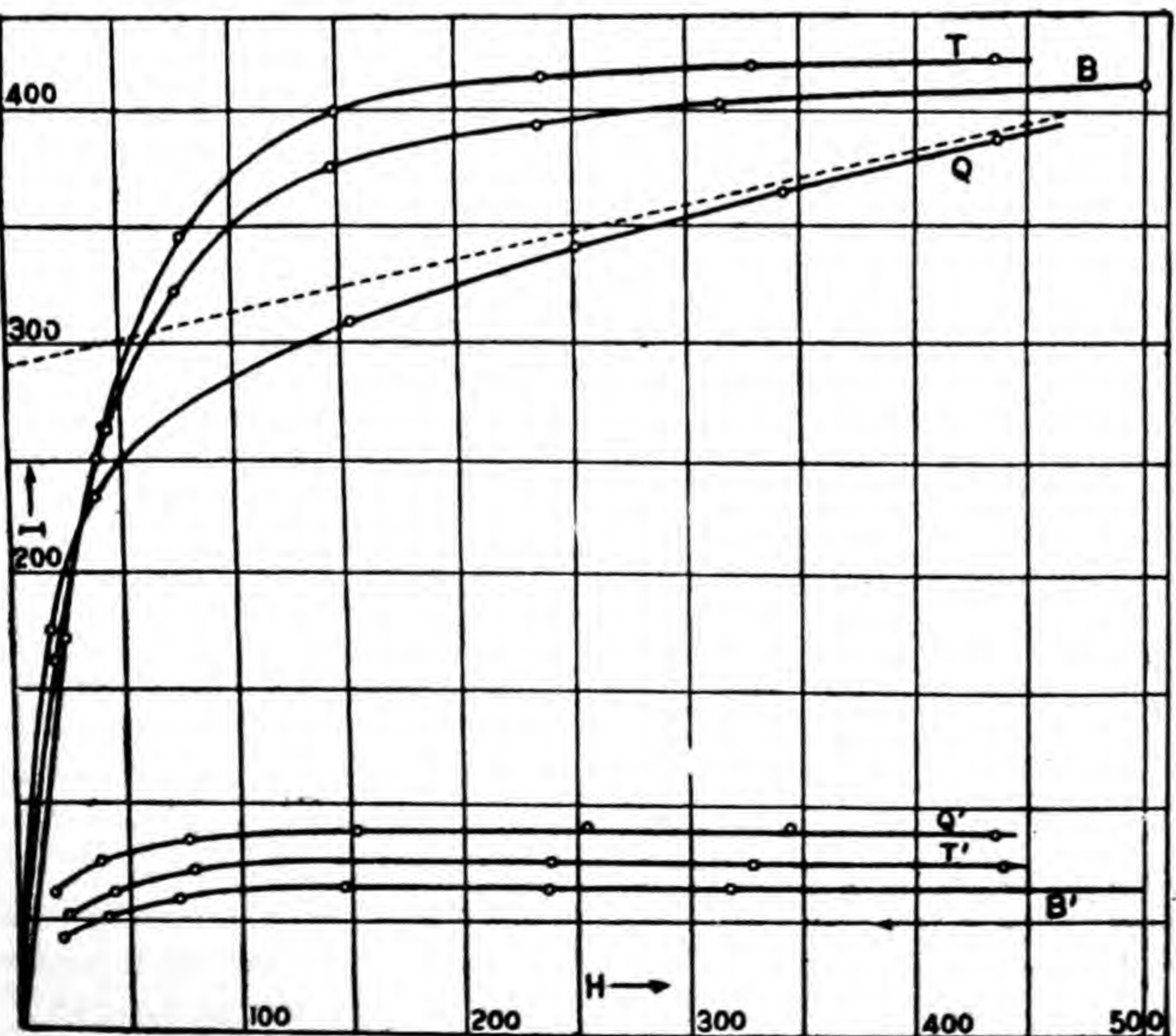


FIG. 55.—Magnetite crystal: Intensity of magnetisation ( $T, B, Q$ ) and residual magnetisation ( $T', B', Q'$ )<sup>(11)</sup>.

$B$  = binary,  $Q$  = quaternary,  $T$  = ternary axis of crystal. Field  $H$  is parallel to the axis considered. Residual magnetisation is with reference to  $H_{max} = 353$ .

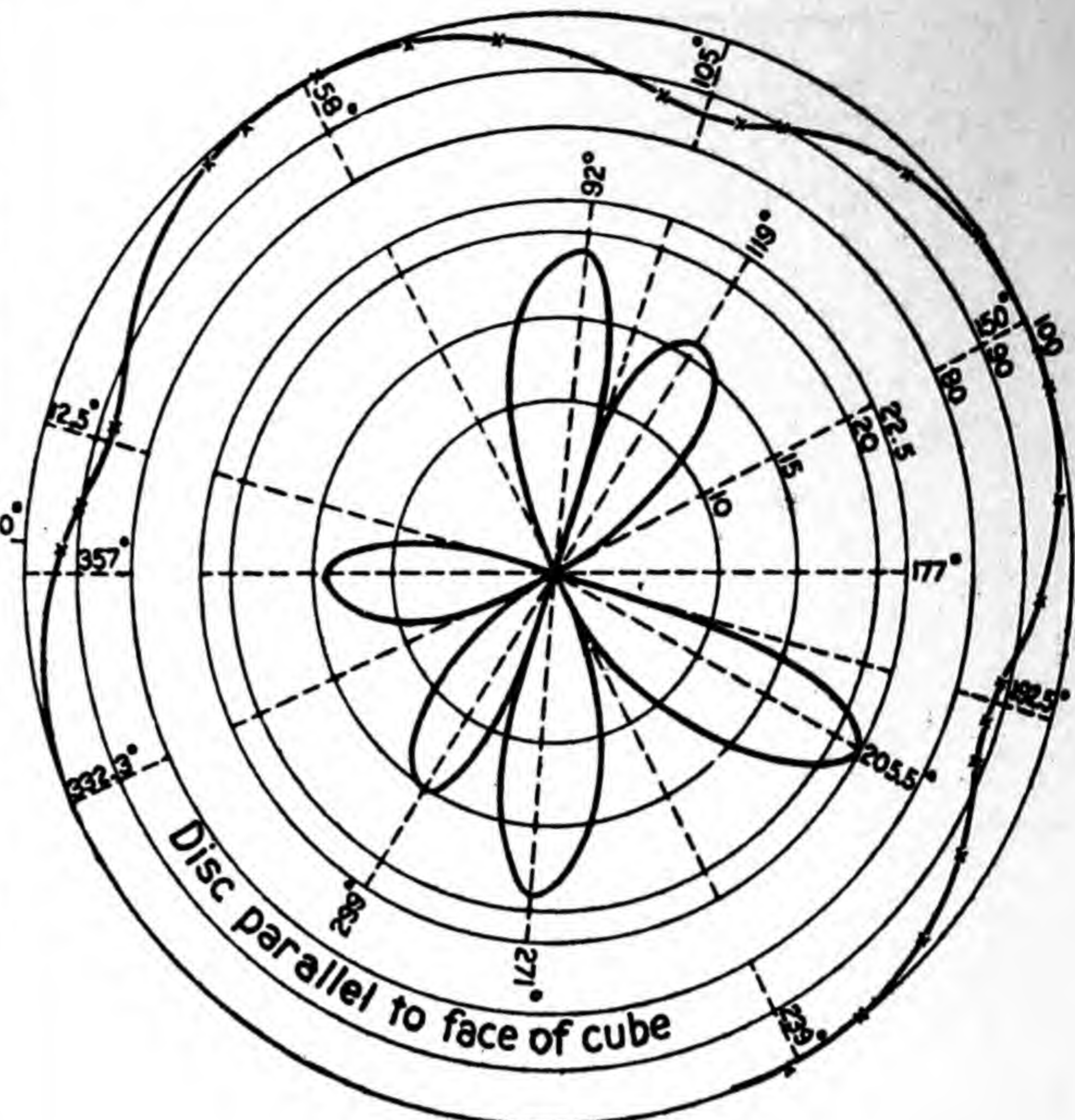


FIG. 56.—(See Fig. 57).

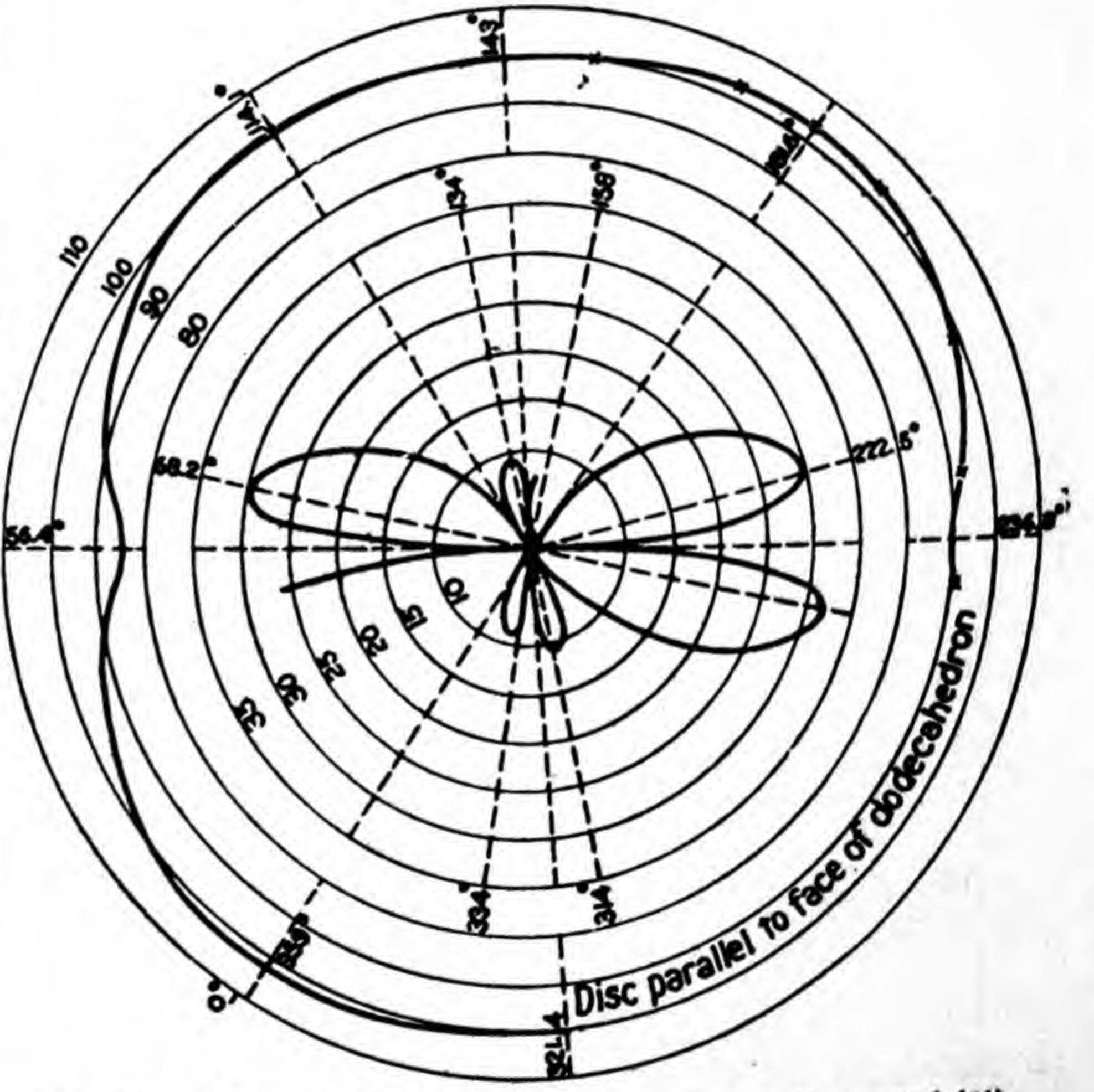


FIG. 57.—Magnetisation of disk cut from magnetite crystal<sup>(11)</sup>. Diameter = 20 mm, thickness = 0.3 mm;  $H = 353$  and lies in plane of disk; azimuth ( $\varphi$ ) of  $H$  is as indicated.  $I$  is proportional to length of radius vector of the curve. Inner loops are magnified 3 times as compared with outer curve. Outer curve is for component of  $I$  parallel to  $H$ ; inner curve is for that perpendicular to  $H$ . Dotted radii indicate positions of maxima and of minima. For the outer curve: In Fig. 56, maxima correspond to binary, and minima to quaternary axes; in Fig. 57, maxima correspond to ternary, and minima to quaternary and binary axes; v. p. 410.



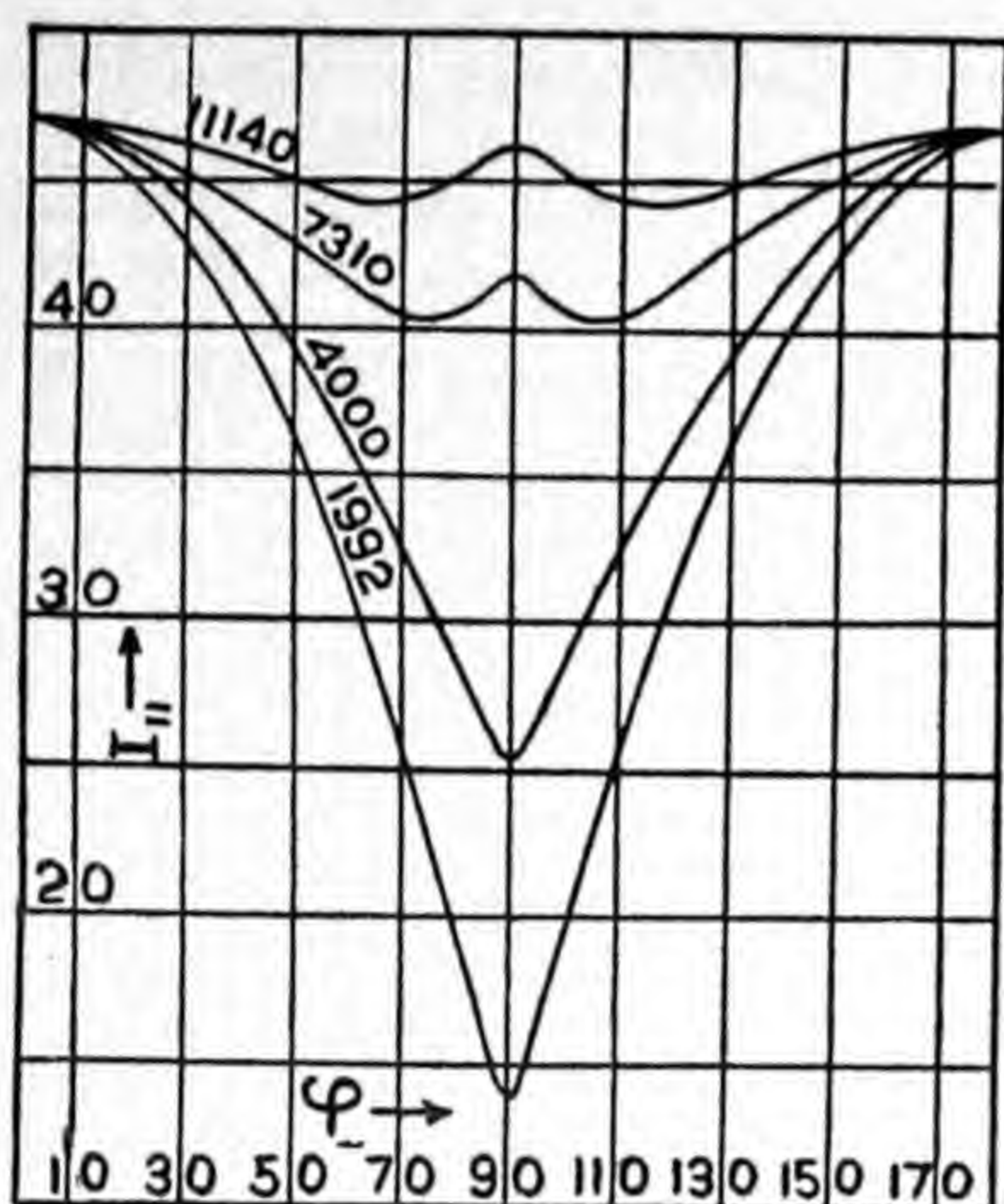


FIG. 58.—Pyrrhotite: Component ( $I_{\parallel}$ ) of the magnetization in the magnetic plane ( $YOX$ ) and parallel to the field ( $H$ ) (72).

$H$  lies in plane  $YOX$ ,  $\varphi$  = azimuth of  $H$  from axis ( $OX$ ) of easy magnetization. Value of  $H$  indicated on each curve.

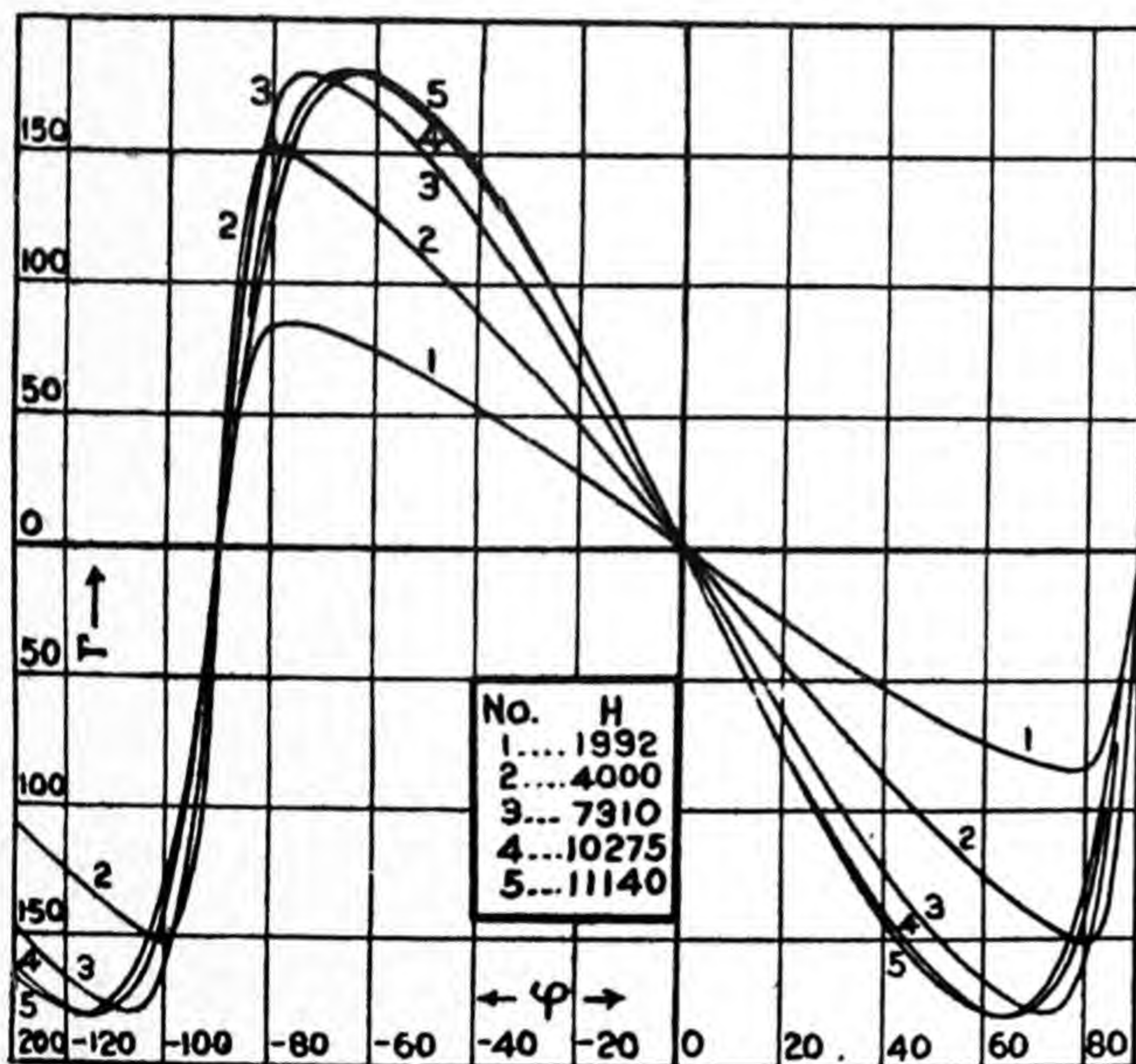


FIG. 59.—Pyrrhotite: Component ( $I_{\perp}$ ) of the magnetization in the magnetic plane ( $YOX$ ) and perpendicular to the field ( $H$ ) (72).

$H$  lies in plane  $YOX$ ,  $\varphi$  = azimuth of  $H$  from axis ( $OX$ ) of easy magnetization.  $I_{\perp} = 950 \text{ G/H}$ .

TABLE 23.—MAGNETIZATION OF ARTIFICIAL MAGNETITE

$t$	$\sigma_s$	Lit.	$t$	$\sigma_s$	Lit.
-253	98.6	(83)	409.0	61.3	(81)
-79	96.9	(74)	497.0	45.7	(81)
+17.2	93.2	(39)	539.5	33.4	(81)
116.4	88.0	(81)	556.6	25.9	(81)
216.0	81.1	(81)	568.0	18.3	(81)
315.5	72.2	(81)	573.0	13.3*	(81)

\* Interpolated. Curie point =  $578.3^\circ\text{C}$ .

( $\text{Fe}_7\text{S}_8$ ), Pyrrhotite. Contains variable amounts of dissolved S; analyses vary from  $\text{Fe}_8\text{S}_8$  to  $\text{Fe}_{16}\text{S}_{17}$ . Definite data can be given only for so-called normal pyrrhotite (compact crystals from Morro Velho,  $d = 4.60$ ); abnormal pyrrhotite (laminar or cleavable, from Bodenmais, etc.) have irregular and complicated properties. Crystals appear to be hexagonal, but magnetic data show that they consist of 3, mutually penetrating, orthorhombic

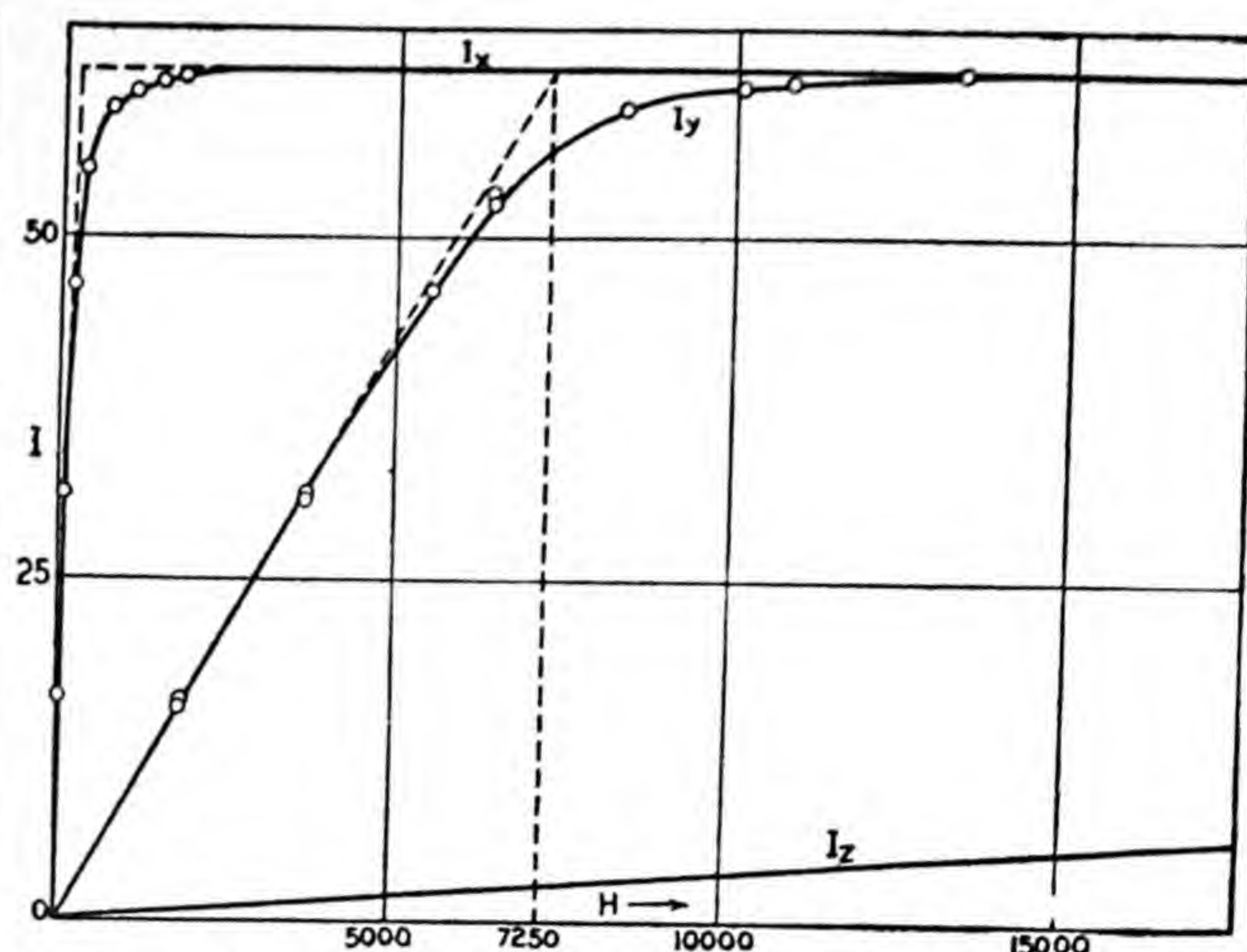


FIG. 60.—Pyrrhotite: Axial magnetization (85).

$I_x$ ,  $I_y$ ,  $I_z$  = intensity of magnetization along the principal axes; in every case  $H$  is parallel to the axis considered. Maximum  $H_{Dy} = 7250$ .

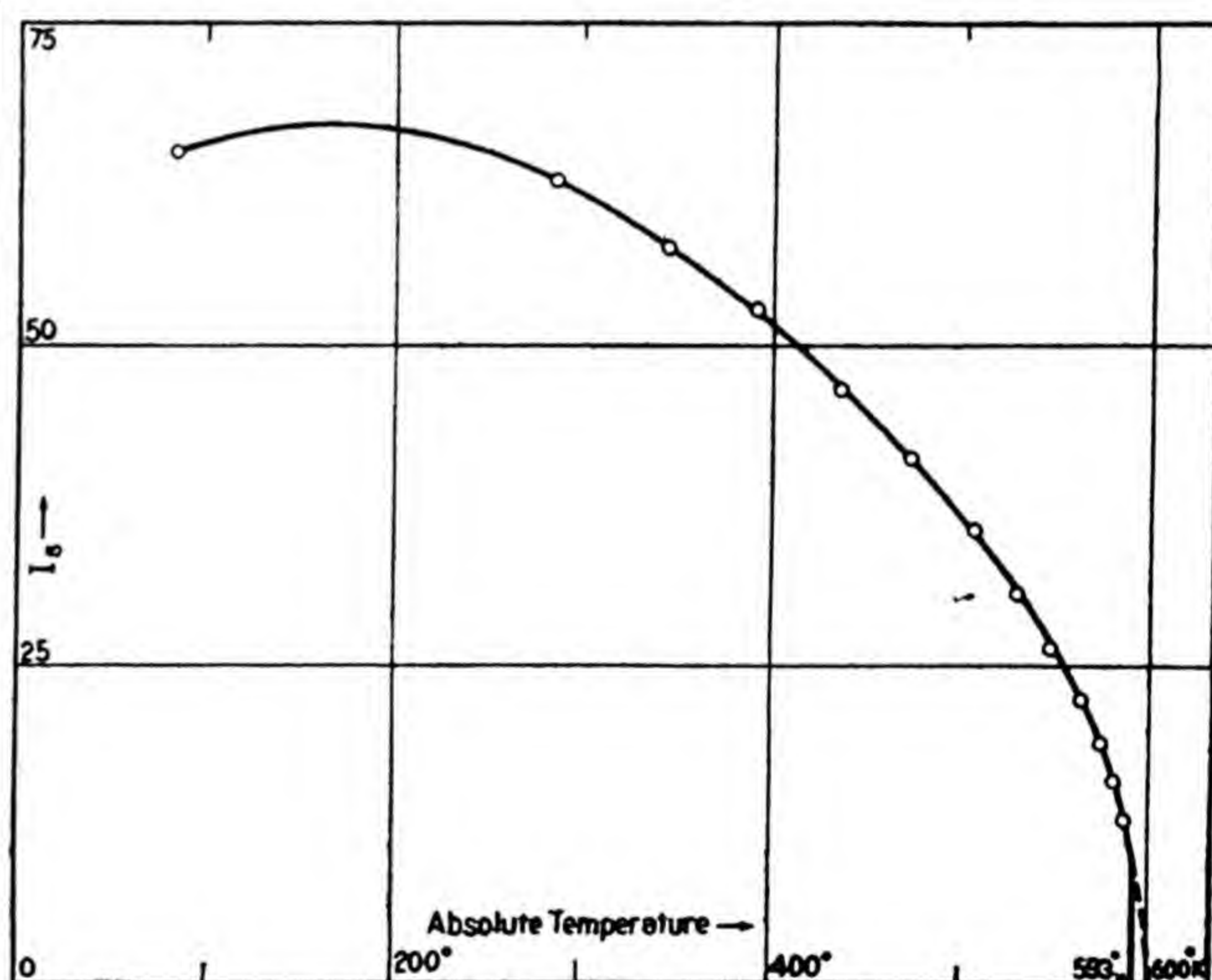


FIG. 61.—Pyrrhotite: Spontaneous magnetization (85).

crystals. The data here given refer to the simple orthorhombic crystal.

Except in very intensive fields,  $I$  lies approximately in a single plane (base of the apparently hexagonal prism) whatever the direction of  $H$ , and the intensity and direction of  $I$  depend only upon the component of  $H$  in this plane, which is called the magnetic plane of the crystal. In this plane, there is a direction ( $OX$ ) in which magnetization is easy; in a direction ( $OY$ ) perpendicular to this, it is difficult. These are the "principal" axes of the crystal. The magnetization of the crystal can be explained by assuming that there is a structural demagnetizing field, component along  $OY$  is  $H_{Dy} = N_y I_y$ , that along  $OZ$  (perpendicular to plane of  $XOY$ ) is  $H_{Dz} = N_z I_z$ , where  $I_y$ ,  $I_z$  are the components of  $I$  along  $OY$ ,  $OZ$ , and  $N_y$ ,  $N_z$  are constants. Maximum values, corresponding to  $I_{\infty}$  are max.  $H_{Dy} = 7300$  gauss (72, 86, 94) and max.  $H_{Dz} = 176\,000$  gauss (74, 95); they are the same for all specimens, but  $I_{\text{max}}$  varies with the specimen (e.g.,  $I_{\text{max}} = 47$ ,



63.6, 72.8 (72), 62 (95)). The coercive force also varies with the specimen ( $H_c = 15.4$  (72), 24 (86), 30 (74)). For the specimen of Fig. 58, 59,  $I_{max.} = 47$ .

Ferromagnetic properties are lost by an allotropic transformation at 318 to 319°C (76), 320°C (95), which is a little above the Curie point.  $N_v$  is independent of the temperature (95); see Figs. 58 to 61.

$Fe_2O_3$ , Hematite. Rhombohedral, is sometimes ferromagnetic. Like pyrrhotite, it has an approximate magnetic plane. For hematite from Kragerö,  $Fe_2O_3 = 93.63\%$ ,  $FeO = 3.26\%$ ,  $TiO_2 = 3.55\%$  (56); for a specimen from same source, the magnetization ( $I_{\perp}$ ) perpendicular, and that ( $I_{\parallel}$ ) parallel to the ternary axis were found (87) to be as follows:

$H$ .....	36	48	60	72
$I_{\perp}$ .....	1.71	1.78	1.83	1.90
$I_{\parallel}$ .....	0.025	0.050	0.073	0.093

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GALVANOMAGNETIC AND THERMOMAGNETIC EFFECTS

ALPHEUS W. SMITH AND L. L. CAMPBELL

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Hall effect.	Effet Hall.	Hall-Effekt.	Effetto Hall.	
Elementary substances.	Substances élémentaires.	Elementare Stoffe.	Elementi.....	416
Miscellaneous materials.	Matières diverses.	Verschiedenes Material.	Materiali vari.....	416
Alloys.	Alliages.	Legierungen.	Leghe.....	417
Variation with temperature: elementary substances.	Variation avec la température: substances élémentaires.	Änderung mit der Temperatur: elementare Stoffe.	Variazioni in funzione della temperatura: elementi.....	417
Variation with magnetic field.	Variation avec le champ magnétique.	Änderung mit dem magnetischen Felde.	Variazioni in funzione del campo magnetico.	418
Corbino effect.	Effet Corbino.	Corbino-Effekt.	Effetto Corbino.....	419
Relation to Hall effect.	Relation avec l'effet Hall.	Beziehung zum Hall-Effekt.	Relazione con l'effetto Hall.....	419
Ettingshausen effect.	Effet Ettingshausen.	Ettingshausen-Effekt.	Effetto Ettingshausen....	419
Nernst effect.	Effet Nernst.	Nernst-Effekt.	Effetto Nernst.	
Elementary substances.	Substances élémentaires.	Elementare Stoffe.	Elementi.....	420
Alloys.	Alliages.	Legierungen.	Leghe.....	420
Variation with temperature.	Variation avec la température.	Änderungen mit der Temperatur.	Variazioni in funzione della temperatura....	421
Righi-Leduc effect.	Effet Righi-Leduc.	Righi-Leduc-Effekt.	Effetto Righi-Leduc.	
Elementary substances.	Substances élémentaires.	Elementare Stoffe.	Elementi.....	421
Alloys.	Alliages.	Legierungen.	Leghe.....	421
Effect of magnetic field upon electrical resistance.	Effet du champ magnétique sur la résistance électrique.	Einfluss des magnetischen Feldes auf den elektrischen Widerstand.	Effetto dei campi magnetici sulla resistenza elettrica.....	421
Effect of magnetic field upon thermal conductivity.	Effet du champ magnétique sur la conductibilité thermique.	Einfluss des magnetischen Feldes auf die thermische Leitfähigkeit.	Effetto di campi magnetici sulla conducibilità termica.....	424



The effects considered are the Hall, Ettingshausen, Nernst, and Righi-Leduc effects, and the changes which a magnetic field produces in the electrical and the thermal conductivities. For a detailed account of the several effects, see (15). Most of these data depend very greatly upon the crystalline structure, purity, and treatment of the material. Variations in these factors, which at present are not specifiable in a satisfactory manner, produce in the numerical data variations which exceed the usual errors of measurement. For this reason, it has not been possible to calculate most probable values from the available data, and it has seemed necessary, for the most part, to tabulate what seemed the most trustworthy values.

If upon a thin, flat, conducting plate  $P$  (width =  $b$ , thickness =  $d$ ), carrying a uniform, constant, longitudinal current (total current =  $I$ ) of either electricity or heat, there be imposed normally a magnetic field of intensity  $H$ , there are set up, for either type of current, two transverse and two longitudinal effects which may be simply expressed in terms of  $H$ ,  $I$ ,  $b$ , and  $d$ . Referring to

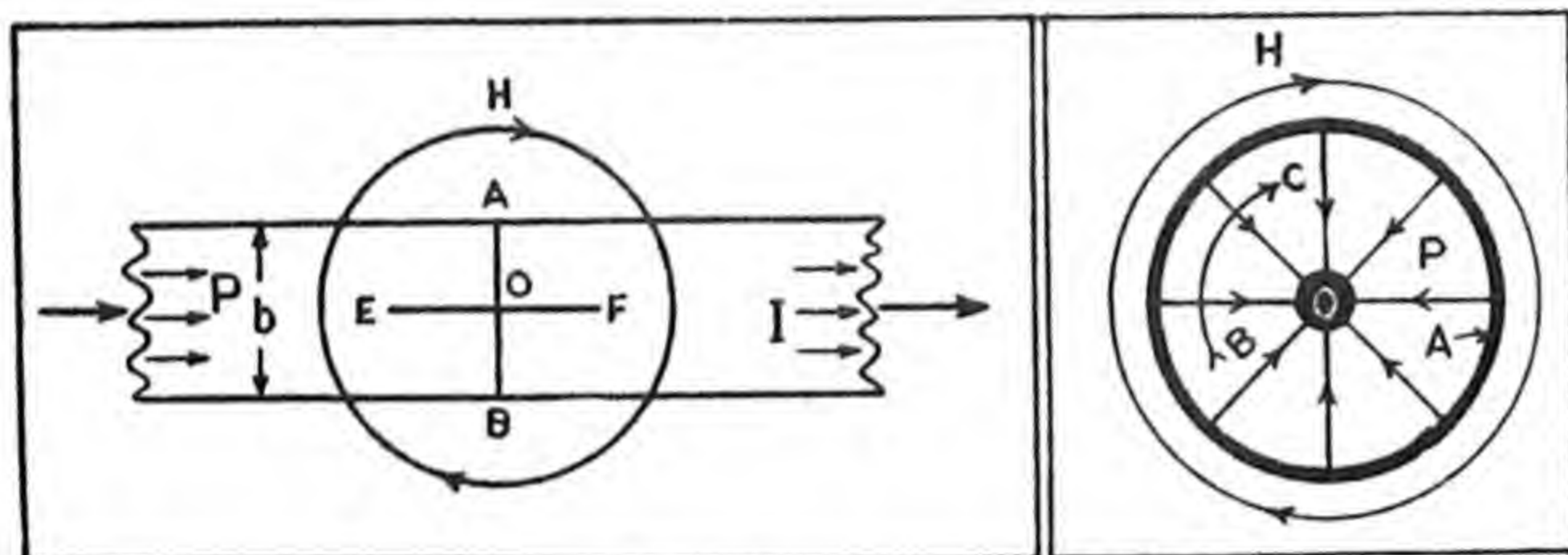


FIG. 1.

FIG. 1.—Diagram for illustrating galvanomagnetic and thermomagnetic effects.  $P$  is a thin, flat, conducting plate of width  $b$  and thickness  $d$ , carrying the uniformly distributed, constant, longitudinal current  $I$  and placed in a uniform, transverse magnetic field  $H$  having the direction that corresponds to Amperian currents flowing in the direction indicated by the arrows on the circle.

FIG. 2.—Diagram illustrating the Corbino effect.  $P$  is a thin, flat circular, conducting ring connecting the massive electrodes  $O$  of radius  $r_1$  and  $A$  of radius  $r_2$ . If, while a uniform radial electric current flows from  $A$  to  $O$ , the plate be subjected to a uniform, transverse magnetic field  $H$  having the direction that corresponds to Amperian currents in the direction indicated by the arrows on the outer circle, a circular current in the direction  $BC$  will be set up if the Corbino effect is positive.

FIG. 2.

Fig. 1, if, in the absence of the field,  $AB$  is an equipotential and an isothermal line, and if the direction of  $H$  is that corresponding to Amperian currents flowing in the direction indicated by the arrows on the circle, then the effects corresponding to the positive values of the several coefficients are as follows:

**Galvanomagnetic Effects.**—( $I$  = current of electricity.) (1) *Hall effect*; coefficient =  $R$ . Potential at  $A$  becomes greater than that at  $B$  by an amount  $E$ ;  $R = Ed/HI$ . (2) *Ettingshausen effect*; coefficient =  $P$ . Temperature at  $A$  becomes higher than that at  $B$  by an amount  $\Delta T$ ;  $P = d\Delta T/HI$ . (3) The difference in potential between  $E$  and  $F$  is changed; that is, the longitudinal electrical resistance is changed. (4) The difference in temperature between  $E$  and  $F$  is changed.

If in measuring the Hall effect, the conditions are such that there is a negligible transfer of heat between the plate and other bodies, the temperature at  $A$  will differ from that at  $B$ , and, for some

substances, the value found for  $R$  will be a little different from that which is found when the strip is maintained at a uniform temperature. The latter is called the *isothermal*, and the former, the *adiabatic* Hall effect.

**Thermomagnetic Effects.**—( $I$  = current of heat;  $dT/dx$  = longitudinal temperature gradient along the plate in the direction opposite to that of the flow of the heat.) (1) *Nernst effect*; coefficient =  $Q$ . Potential at  $A$  becomes greater than that at  $B$  by an amount  $E$ .  $Q = E/[Hb(dT/dx)]$ . (2) *Righi-Leduc effect*; coefficient =  $S$ . Temperature at  $A$  becomes greater than that at  $B$  by an amount  $\Delta T$ .  $S = \Delta T/[Hb(dT/dx)]$ . (3) The difference in potential between  $E$  and  $F$  is changed. (4) The difference in temperature between  $E$  and  $F$  is changed; that is, the longitudinal thermal conductivity is changed.

If either  $E$  or  $\Delta T$  is negative, so is the corresponding coefficient. By multiplying the expressions for  $Q$  and  $S$  by the heat conductivity per unit length of the plate, they become of the same form as the expressions for  $R$  and  $P$ .

**Hall Effect** (31) ( $R$ ).—Differences in the values obtained, under apparently the same conditions, by different observers may be due to the presence of impurities, or to differences in the physical condition of the material. For *non-magnetic metals*, with the exception of  $Sb$ ,  $Bi$ , and  $Te$ ,  $R$  varies very little with  $T$  and practically not at all with  $H$ . For the *ferromagnetic metals*,  $R$ , generally, increases with  $T$  until the Curie point is reached, then it decreases rapidly, and probably becomes 0 at the melting point; for  $T$  constant,  $R$  at first is independent of  $H$ , then decreases as  $H$  increases, and in higher fields approaches a limiting value.

**Corbino Effect** (18).—If, instead of being longitudinal, the electric current ( $I$ ) radiates from  $O$  (Fig. 2), the imposition of  $H$  sets up a circular current around  $O$ . This is the *Corbino effect*. If the plate is a circular annulus of radii  $r_1$  and  $r_2$  ( $r_1 < r_2$ ), if the radial current has a uniform angular distribution, the total current towards the center being  $I$ , and if the field ( $H$ ) is uniform over the entire plate, then the total value of the circular current ( $C$ ) set up in the plate in the direction of the Amperian currents corresponding to  $H$  is  $C = \frac{cHI}{2\pi} \log_e \frac{r_2}{r_1}$ ;  $c$  is the Corbino constant.

On Adams' theory (1)  $c = \mu_0 e t_0 / 2m$ , where  $t_0$  = free time of an electron,  $\mu_0$  is the magnetic permeability of a vacuum, and  $e$  and  $m$  are the charge and mass of an electron. In many cases,  $t_0$  is negative; this means that the theory is not satisfactory. Fundamentally, the Corbino and the Hall effects are of the same nature (1), but it is the product of  $c$  times the specific resistance of the plate, which is comparable with  $R$  (17).

**Change in Resistance.**—When a conductor is placed in a magnetic field ( $H$ ), its resistance ( $r$ ) in any specified direction with reference to  $H$  is increased by an amount which may vary with the direction of the field. For *non-magnetic* metals and alloys,  $\Delta r/r$ , at constant temperature, is nearly proportional to  $H^2$ . Writing  $\Delta r/r = CH^2$ ,  $C$  is generally of the same sign (+ for pure metals, − for alloys) for all directions; its numerical value increases rather rapidly as the temperature is reduced, and varies only slightly, if at all, with  $H$ . For  $Bi$ ,  $Sb$ , and graphitic  $C$ , the relation between  $\Delta r$  and  $H$  is abnormal. For *ferromagnetic* metals,  $\Delta r/r$ , except at extremely low temperatures, is nearly proportional to the intensity of magnetization. For  $Co$  and  $Ni$ ,  $\Delta r$  is negative if transverse to the field, and positive if parallel to it. As the field is increased, the numerical value of  $\Delta r$  increases in both cases, approaching a limiting value in intense fields. As the transverse field is increased,  $\Delta r$  changes at first slowly, then more rapidly, and finally slowly again. As the longitudinal field is increased,  $\Delta r$  changes rapidly at first, then more slowly. Small errors in the orientation of the transverse field lead to positive values of  $\Delta r$  in weak fields; this may account for some of the reported initial positive values of  $\Delta r$  in transverse fields. Iron behaves differently.



TABLE 1.—HALL EFFECT ( $R$ ): ELEMENTARY SUBSTANCES

$R = Ed/HI$ ;  $R = A \times 10^{-9}$ ;  $t_R$  = room temperature; unit of  $H = 1000$  cgs = 1 kilogauss; of  $R = 1$  cgs =  $10^{-9}$  volt-cm/ampere-gauss;  $t$  = temperature, °C.

	$t$	$H$	$A$	$n$	Lit.
Ag.....	$t_R$	9 to 12	— 8.32	4	(20)
	$t_R$	*	— 8.38	4	(74)
	20	5 to 11	— 8.97	4	(80)
	17	10	— 7.95	4	(7)
Al.....	$t_R$	9	— 3.85	4	(20)
	14	21	— 3.96	4	(74)
	18	*	— 3.90	4	(3)
As.....	20	4 to 8	+ 4.52	2	(46)
Au.....	25	9.3	— 7.04	4	(34)
	$t_R$	9.0	— 7.11	4	(20)
	18	*	— 7.04	4	(3)
	17	12	— 7.24	4	(7)
Bi.....	20	1.13	— 10.1	0	(20)
	18	10.6	— 4.82	0	(79)
	14.5	0.89	— 5.78	0	(73)
C.....	$t_R$	4 to 11	— 1.73	1	(20)
	90	10.3	— 1.6	1	(79)
	17	11.8	+ 7.4†	1	(57)
Cd.....	$t_R$	9 to 12	+ 5.5	4	(20)
	$t_R$	*	+ 8.8	4	(74)
	18	*	+ 5.89	4	(3)
	17	12.0	+ 5.5	4	(57)
Ce.....	24	17.5	+ 1.92	3	(68)
Co.....	$t_R$	*	+ 2.45	3	(74)
	24	4.4	+ 1.61§	3	(79)
	25	9.3	+ 3.72	3	(34)
Cu.....	16	8 to 22	— 5.47	4	(74)
	$t_R$	12.0	— 5.19	4	(20)
	20	*	— 5.4	4	(79)
	20	5 to 11	— 4.28	4	(80)
	18	*	— 5.28	4	(3)
	17	10	— 4.92	4	(7)
Fe†.....	13	8 to 15	+ 9.08	3	(74)
	12.9	5.3	+ 7.94	3	(35)
	18	6.3	+ 10.8	3	(79)
	22	17.0	+ 11.0	3	(64)
	18	*	+ 11.2	3	(3)
	$t_R$	2.5	+ 17.5	3	(20)
	$t_R$	5 to 11	+ 13.4	3	(80)
In.....	24	17.5	— 0.73	4	(68)
Ir.....	20	5 to 11	+ 4.02	4	(80)
	20	5 to 11	+ 3.64	4	(80)
Li.....	24	17.5	— 1.70	3	(68)
Mg.....	$t_R$	7.4	— 9.4	4	(20)
Mn.....	$t_R$	*	— 9.3	4	(81)
Mo.....	24	17.5	+ 1.26	3	(68)
Na.....	$t_R$	8.7	— 2.5	3	(20)
Ni.....	37.5	9.3	— 5.10	3	(34)
	14	2.0	— 8.46	3	(74)
	18	6.3	— 12.5	3	(79)
	18	10.6	— 4.69§	3	(79)
	18	*	— 4.70	3	(3)
Pb.....	20	11 to 16	+ 0.9	4	(20)
	—269	11.3	+ 1.8	4	(57)
Pd.....	25	9.3	— 8.44	4	(34)
	20	5 to 11	— 6.91	4	(80)
	20	6 to 13	— 11.5	4	(20)
	20	5 to 11	— 11.1	4	(80)
	17	9.8	— 6.80	4	(7)

TABLE 1.—(Continued)

	$t$	$H$	$A$	$n$	Lit.
Pt.....	20	12.0	— 2.4	4	(20)
	20	5 to 11	— 1.27	4	(80)
	18	*	— 2.02	4	(3)
Sb.....	20	4 to 16	+ 1.92	1	(20)
	21.5	1.8	+ 2.19	1	(5)
	18	*	+ 2.19	1	(79)
	18	*	+ 1.25	1	(3)
Si.....	23	20	+ 41.0	0	(64)
	50	9	+ 23.0	0	(13)
	18.7	6.2	+206.0¶	0	(28)
	18.7	6.2	+120.0**	0	(28)
Sn.....	$t_R$	4	— 0.2	4	(32)
	$t_R$	5.0	— 0.36	4	(20)
	—269	11.3	+ 0.26	4	(57)
Ta.....	24	17.5	+ 1.01	3	(68)
Te.....	20	3 to 9	+530.0	0	(20)
	27	5	+784.0	0	(77)
	22	8.8	+536.0	0	(67)
	20	8.8	+621.0	0	(67)
Tl.....	24	17.5	+ 2.4	4	(68)
W.....	24	17.5	+ 1.18	3	(68)
Zn.....	$t_R$	6 to 10	+ 4.10	4	(20)
	16	8 to 21	+ 9.53	4	(74)
	20	5 to 11	+ 10.4	4	(80)
	22	25	+ 3.3	4	(5)

\* Magnetic field not stated by observer.

† Graphite.

‡ Recent observations (76.1) show that in single crystals of Fe,  $R$  varies but little with the directions of the axes of the crystal, and differs but little from its value for soft iron.

§ Electrolytic.

|| Steel.

¶ Isothermal.

\*\* Adiabatic.

TABLE 2.—HALL EFFECT ( $R$ ): MISCELLANEOUS MATERIALS

For elementary substances and alloys, see Tables 1 and 3;  $R = A \times 10^9$ ;  $\rho$  = volume resistivity of  $\text{Cu}_2\text{I}_2 + k\text{I}$ ; unit of  $R = 1$  cgs =  $10^{-9}$  volt-cm/ampere-gauss; of  $\rho = 1$  ohm-cm.

Material	$t$	$A$	$n$	Lit.	$\text{Cu}_2\text{I}_2 + k\text{I}$ (72)		
					$\rho$ †	$A$ †	$n$
$\text{Cu}_2\text{I}_2$ , Cuprous iodide.....	18	+ 11	+3	(72)	0.02	55	—2
					0.049	20	—1
$\text{FeS}_2$ , Pyrites.....	18	—296	—3	(67)	0.12	69	—1
$\text{MoS}_2$ , Molybdenite.....	18	—260*	+1	(41)	2.91	34	+1
	18	—260*	+1	(41)	0.212	20	+1
	90	— 88*	+1	(41)	7.50	88	+1
	18	—131†	+1	(41)	94.0	11	+3
	90	— 49†	+1	(41)			
	18	—303*	+1	(28)			
	90	—878*	0	(28)			
	18	—152†	+1	(28)			
	90	—481†	0	(28)			

\* Adiabatic.

† Isothermal.

‡  $\text{Cu}_2\text{I}_2$  dissolves I; both  $\rho$  and  $A$  decrease as the amount of the dissolved I increases; amount of I dissolved is not stated.



TABLE 3.—HALL EFFECT ( $R$ ): ALLOYS

$C_1$  = proportion of constituent (1); unit of  $C_1$  = 1% by wt.;  
 $R = 10^{-3}$  cgs =  $10^{-12}$  volt-cm/ampere-gauss;  $H = 1000$  cgs = 1 kilogauss; temperatures ( $t$ ) in °C.

Alloy	$C_1$	$R$			
	$t =$	-258.6°	-252.8°	-183°	+17°C
(1) Au, Gold	0	-0.99	-1.015	-0.82	-0.80
	3.95	-0.69	-0.695	-0.74	-0.77
(2) Ag, Silver (55, 56)	15.47	-0.575	-0.575	-0.645	-0.735
	44.28	-0.44	-0.45	-0.52	-0.60
	81.00	-0.37	-0.36	-0.47	-0.56
	93.84	-0.37	-0.37	-0.525	-0.56
	98.89	-0.65	-0.67	-0.66	-0.68
	100.00	-0.98	-0.98	-0.76	-0.72

Alloy	$C_1$	$R$
(1) Cu, Copper	0	+0.830
	6	+0.496
(2) Zn, Zinc (33)	67	-0.116
	73	-0.250
	81.3	-0.404
	100	-0.520

(1) Fe, Iron	92.95	+15.2
	93.84	+15.6
(2) Cu, Copper (69)	96.0	+16.3
	98.0	+19.0
	98.49	+21.0
	99.196	+12.2
	100	+11.2

(1) Ni, Nickel	50	-1.33
	65	-6.31
(2) Cu, Copper (69)	70	-41.9
	75	-83.7
	85	-59.1
	90	-52.0
	92.5	-40.9
	95	-29.8
	100	-7.65

(1) Ni, Nickel	0	+11.2
	1.07	+16.9
(2) Fe, Iron (69)	1.93	+17.8
	7.05	+42.5
	8.17	+43.1
	10.20	+52.0
	13.11	+61.5
	56.0	+46.9

(1) Sn, Tin	0	-9.84
	0.95	-1.76
(2) Bi, Bismuth; unit of $R = 1$ cgs = $10^{-3}$ volt-cm per ampere-gauss (22).	1.46	-0.69
	0	-7.20
	0.95	-0.53
	1.46	-0.07
	6.14	+0.01
	$H = 6$ kilogauss	
	0	-4.98
	0.95	+0.12
	1.46	+0.36
	6.14	+0.09
	$H = 11$ kilogauss	

Constantan (80) 60Cu + 40Ni  
 $R = -0.9$

Monel (67)*		
$H$	$t$	$R$
1.65	25	-35.1
1.65	66	-24.2
3.15	96	-9.62
5.30	137	-2.38

Nichrome (67)		
$H$	$t$	$R$
3.3	17	+199
3.3	120	+209
1.05	198	+200
1.05	216	+113
3.3	246	+21.2
5.5	286	+8.6

German silver (21)  
 50Cu + 30Zn + 20Ni  
 $R = -0.54$

Manganin (27)		
$H$	$t$	$R$
4.1	150	0.569†
4.79	440	0.432†
4.92	810	0.460†

Heusler alloy† (81)  
 25Mn + 15Al + 60Cu  
 $R = +13.0$

\* Ni, 68%; Cu, 29.5%; Fe, 1.5%; Mn, 1%.  
 † Sign of  $R$  is not given by observer.  
 ‡  $R$  is +, but for each constituent it is -

TABLE 4.—(Continued)

Al, Aluminium		
$T$	$R$	Lit.
20	-24.8	(3)
83	-20.0	(3)
194	-39.0	(3)
291	-39.0	(3)
83	-19.2	(64)
298	-32.0	(64)

Au, Gold		
20	-85.7	(3)
83	-72.6	(3)
194	-71.2	(3)
291	-70.4	(3)
14.5	-98.2	(7, 55, 56)
20.3	-98.1	(7, 55, 56)
290	-72.4	(7, 55, 56)
83	-72.5	(64)
298	-70.4	(64)
298	-70.4	(34)
328	-69.9	(34)

Bi, Bismuth  
 See Table 5

C, Carbon  
 See Table 5

Cd, Cadmium		
20	+203	(3)
83	+79.5	(3)
194	+60.5	(3)
291	+58.9	(3)
14.5	+191	(57)
20.5	+176	(57)
290	+55	(57)

Co, Cobalt  
 See Table 5

Cu, Copper		
20	-60.5	(3)
83	-79.2	(3)
194	-55.3	(3)
291	-52.8	(3)
14.5	-65.6	(7)
20.3	-66.2	(55, 56)
290	-49.2	(55, 56)

Cu.—(Continued)		
$T$	$R$	Lit.
83	-65	(64)
296	-54	(64)
289	-53.2	(74)
373	-54.6	(74)

Fe, Iron  
 See Table 5

Ni, Nickel  
 See Table 5

Pb, Lead		
2.8	+13	(57)
4.25	+18	(57)

Pd, Palladium		
14.5	-138.5	(7, 55, 56)
20.3	-136.8	
290	-67.5	
83	-109	(64)
296	-86	(64)
298	-84.4	(34)
318	-85.5	(34)
338	-84.3	(34)

Pt, Platinum		
20	-19.9	(3)
83	-19.8	(3)
194	-9.04	(3)
291	-20.2	(3)
83	-22.2	(64)
296	-20.2	(64)

Sb, Antimony  
 See Table 5

Sn, Tin		
2.8	+9.8	(57)
4.25	+2.6	(57)

Te, Tellurium  
 See Table 5

Zn, Zinc		
83	+109	(64)
298	+63	(64)
353	+53.0	(27)
473	+44.6	(27)
673	+63.4	(27)
289	+94.6	(74)
374	+85.2	(74)

TABLE 4.—VARIATION OF HALL EFFECT ( $R$ ) WITH TEMPERATURE ( $T$ )

A-Table.—Elementary Substances

Unit of  $R = 10^{-3}$  cgs =  $10^{-12}$  volt-cm/ampere-gauss;  $T$  is abs. temp., °K

Ag, Silver		
$T$	$R$	Lit.
2.8	-160	(57)
4.25	-160	(57)
14.5	-99.1	(55, 56)
20.3	-101.4	(55, 56)
290	-80	(55, 56)
83	-92	(64)
296	-84	(64)

TABLE 5.—VARIATION OF HALL EFFECT ( $R$ ) WITH TEMPERATURE ( $T$ ): BI, C, CO, FE, NI, SB, AND TE

$R = A \times 10^3$  cgs =  $A \times 10^{-9}$  volt-cm/ampere-gauss;  $T$  = abs. temp., °K

Bi, Bismuth; $n = 0$		
$T$	$A$	Lit.
4.25	-86.3	(57)
287.5	-5.78	(73)
377	-2.83	(73)
530	-1.13	(73)
543	-0.25	(73)
14.6	-69.5	(7, 55, 56)
20.3	-59.0	(7, 55, 56)
73.0	-33.5	(7, 55, 56)
90.0	-24.6	(7, 55, 56)
290.0	-5.66	(7, 55, 56)
C, Carbon (Graphite); $n = 0$		
$T$	$A$	Lit.
14.5	+1.52	(57)
20.5	+2.22	(57)
290	+0.74	(57)
Co, Cobalt; $n = -3$		
298	+3.72	(34)
318	+4.34	(34)
83	+1.51	(64)
296	+5.88	(64)
373	+8.65	(64)
457	+13.6	(64)



TABLE 5.—(Continued)

Co.—(Continued)			Ni.—(Continued)		
<i>T</i>	<i>A</i>	Lit.	<i>T</i>	<i>A</i>	Lit.
573	+ 21.2	(64)	20.3	− 0.468	(7, 55, 56)
789	+ 48.3	(64)	90	− 0.798	(7, 55, 56)
933	+ 89.4	(64)	290.5	− 4.37	(7, 55, 56)
1113	+158	(64)	83	− 1.85	(64)
1233	+200	(64)	296	− 12.7	(64)
1303	+170	(64)	373	− 16.3	(64)
1373	+ 60	(64)	457	− 23.4	(64)
Fe, Iron; † <i>n</i> = −3			573	− 40.8	(64)
20	+ 1.44	(3)	628	− 56.0	(64)
83	+ 1.33	(3)	658	− 58.9	(64)
194	+ 4.99	(3)	666	− 19.2	(64)
291	+ 11.23	(3)	683	− 4.5	(64)
83	+ 0.75	(64)	819	− 0.7	(64)
295	+ 11.0	(64)	310	− 5.10	(34)
373	+ 18.9	(64)	330	− 5.93	(34)
457	+ 29.2	(64)	350	− 6.83	(34)
573	+ 50.4	(64)	Sb, Antimony; <i>n</i> = −3		
818	+167	(64)	20	+152	(3)
917	+243	(64)	83	+163	(3)
1008	+319	(64)	194	+140	(3)
1069	+120	(64)	291	+125	(3)
1108	+ 32.8	(64)	87	+245	(5)
1173	+ 9	(64)	194	+235	(5)
286	+ 7.94	(35)	295	+209	(5)
358	+ 14.86	(35)	331	+203	(5)
Ni, Nickel; † <i>n</i> = −3			Te, Tellurium; <i>n</i> = 0		
20	− 1.52	(3)	14.5	+211	(7, 55, 56)
83	− 1.38	(3)	20.3	+214.5	(7, 55, 56)
194	− 2.80	(3)	89	+210.5	(7, 55, 56)
291	− 4.70	(3)	291	+185.5	(7, 55, 56)
4.25	− 0.00+	(57)			

\* See also Fig. 5. † See also Fig. 3. ‡ See also Fig. 4.

TABLE 6.—VARIATION OF HALL EFFECT (*R*) WITH MAGNETIC FIELD (*H*)

Cf. p. 416, 417 and Figs. 3, 4, 5; *T* = abs. temp., °K; *t* = centigrade temp., °C; unit of *R* = 1 cgs = 10<sup>−8</sup> volt-cm/ampere-gauss; *H* = 1000 cgs = 1 kilogauss.

Bi, Bismuth (26)					
<i>H</i> \ <i>T</i>	91°	183°	250°	284.5°	373°K
1	−62.2	−28.0	−17.0	−13.3	−7.28
2	−55.0	−25.0	−16.0	−12.7	−7.17
3	−49.7	−22.9	−15.1	−12.1	−7.06
4	−45.8	−21.5	−14.3	−11.55	−6.95
5	−42.6	−20.2	−13.6	−11.05	−6.84
6	−40.1	−18.9	−12.9	−10.6	−6.72

Bi (5)		Sb, Antimony (5)	
<i>H</i> \ <i>t</i>	14	<i>H</i> \ <i>t</i>	21.5
2	−3.8	0.14	+0.26
4	−3.3	0.72	+0.21
6	−3.0	1.75	+0.21
8	−2.7	4.31	+0.208
10	−2.4	8.19	+0.201
11	−2.3	10.20*	+0.199

19.2, *R* = +0.189; *H* = 24.7, *R* = +0.186.

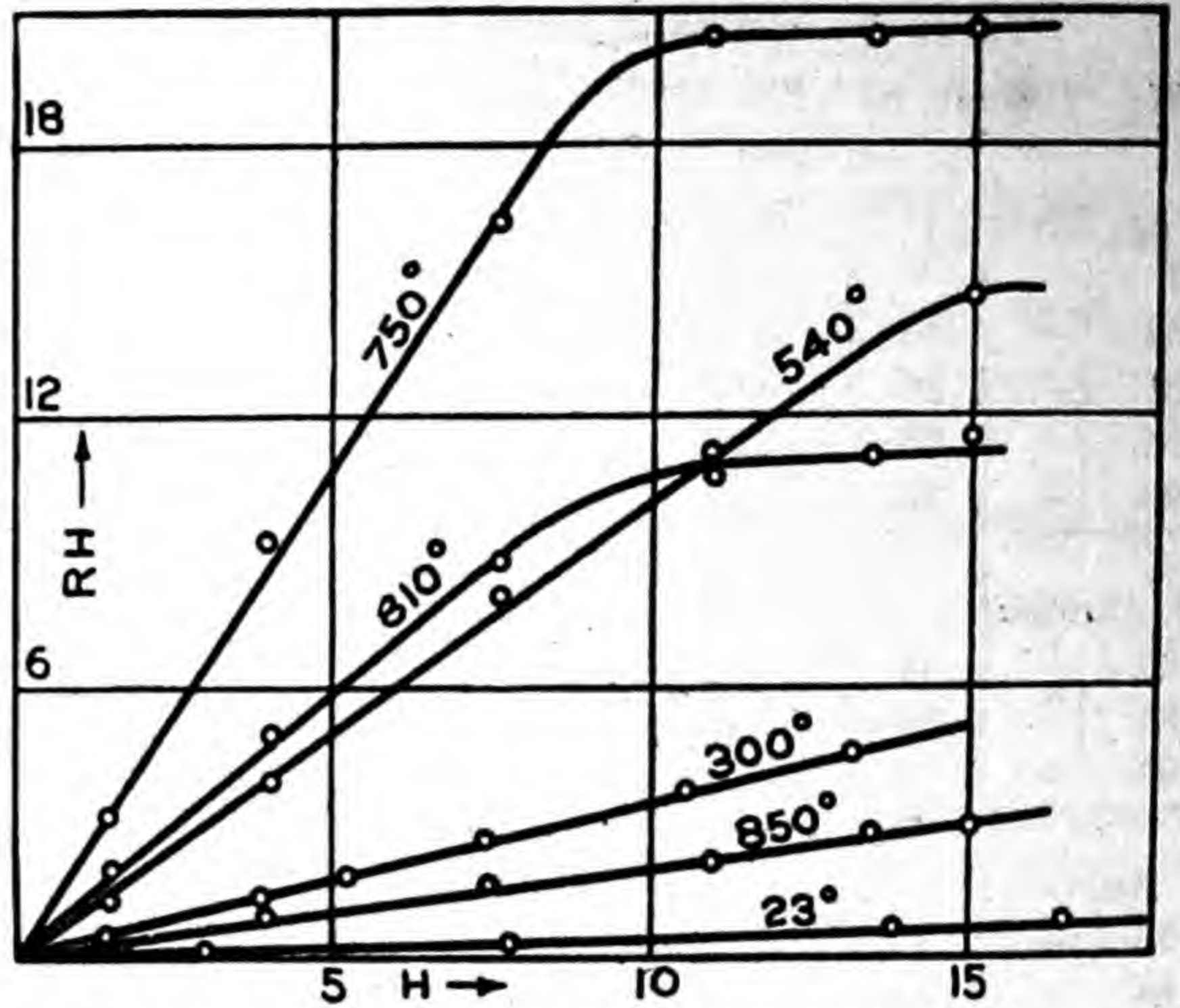


FIG. 3.—Hall effect (*R*) in electrolytic iron (\*). Unit of *RH* is undetermined, of *H* = 1 kilogauss; temperatures are °C; see also Tables 1, 5.

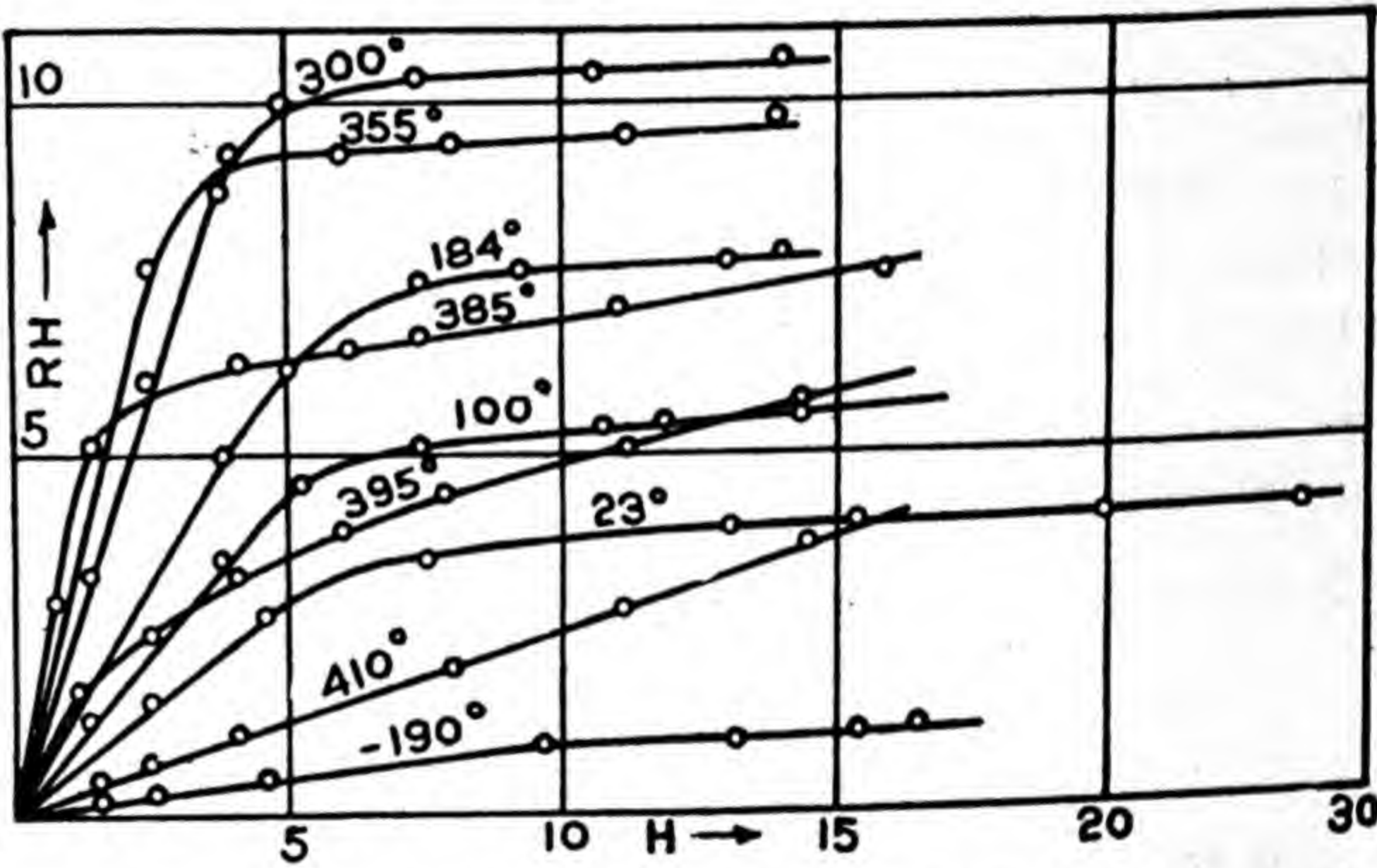


FIG. 4.—Hall effect (*R*) in nickel (\*). Unit of *RH* is undetermined, of *H* = 1 kilogauss; temperatures are °C; see also Tables 1, 5.

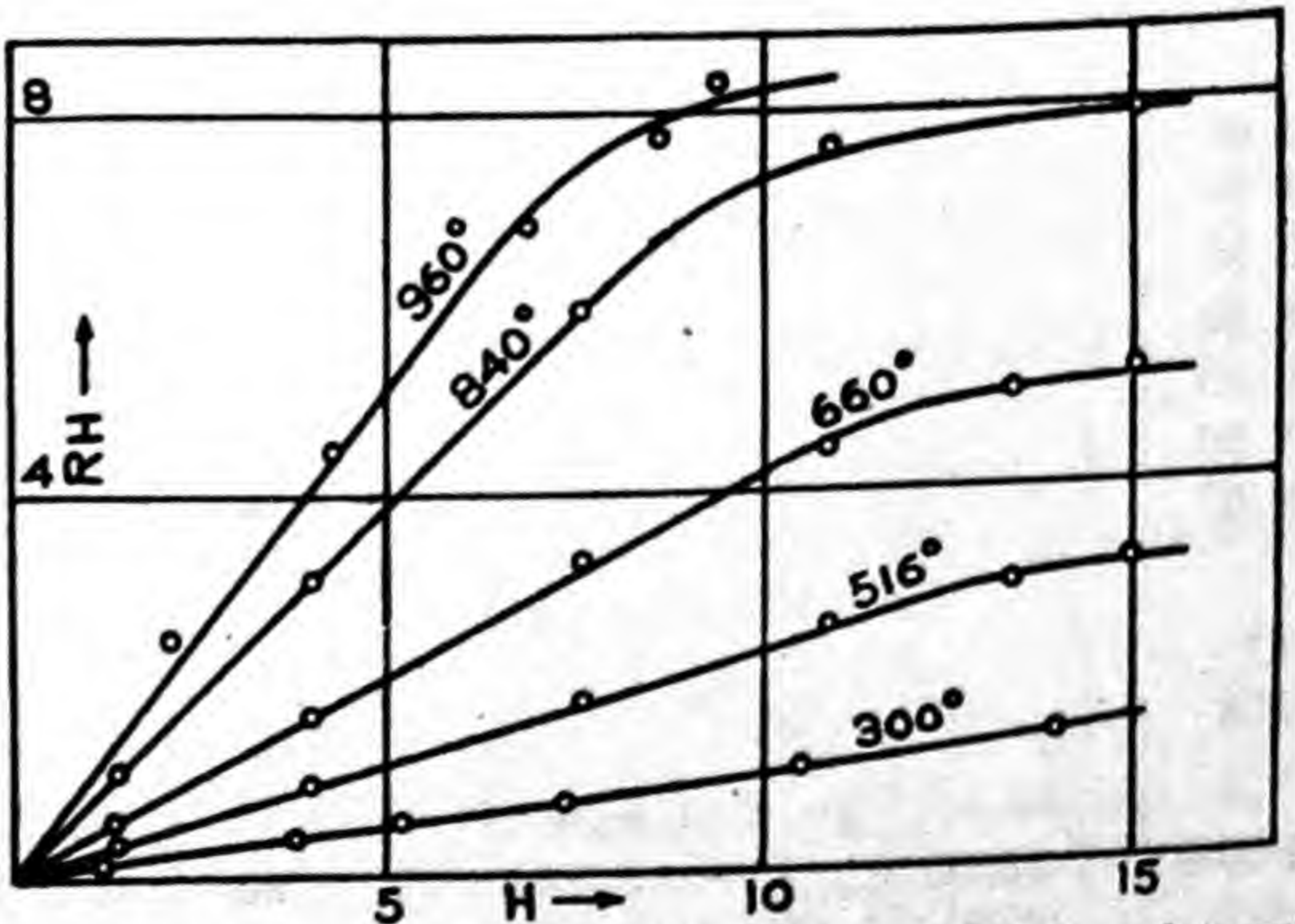


FIG. 5.—Hall effect (*R*) in cobalt (\*). Unit of *RH* is undetermined; of *H* = 1 kilogauss; temperatures are °C; see also Tables 1, 5.



TABLE 7.—CORBINO EFFECT ( $c$ ) (2, 17)

See Fig. 2; unit of  $H = 1000$  cgsu = 1 kilogauss;  $c = 10^{-7}$  cgsu =  $10^{-7}$  gauss $^{-1}$

Ag, Silver		Bi.—(Continued)		Fe.—(Continued)	
$H$	$c$	$H$	$c$	$H$	$c$
4.58	— 4.84	5.82	— 443	6.75	+ 6.58
5.51	— 4.86	6.54	— 415	7.62	+ 6.60
6.24	— 5.05	7.72	— 381	8.45	+ 7.13
6.90	— 4.78	Cd, Cadmium		Ni, Nickel*	
Al, Aluminium		7.21	+ 0.715	2.57	— 14.4
5.66	— 0.83	Co, Cobalt		3.73	— 14.5
6.85	— 0.69	5.36	+ 2.63	4.81	— 14.6
7.97	— 0.77	6.69	+ 2.61	5.97	— 13.0
Au, Gold		7.57	+ 2.48	6.93	— 11.76
5.25	— 2.06	Cu, Copper		Pt, Platinum	
6.64	— 1.99	2.82	— 3.36	7.06	— 0.199
Bi, Bismuth		4.22	— 2.40	Sb, Antimony	
0.03	— 711	5.92	— 2.61	2.59	+ 40.9
0.107	— 739	6.75	— 2.51	4.38	+ 40.7
0.419	— 771	7.31	— 2.38	6.18	+ 38.3
0.953	— 666	Fe, Iron		7.21	+ 37.5
2.63	— 613	1.39	+ 7.45	Zn, Zinc	
4.69	— 520	2.06	+ 8.27	7.47	+ 0.343
		3.30	+ 6.55		
		4.89	+ 6.64		

TABLE 8.—RELATION BETWEEN HALL ( $R$ ) AND CORBINO ( $c$ ) EFFECTS, AND FREE TIMES ( $t_0$ ) OF ELECTRONS

Illustrative only; see p. 415; same specimen used for  $R$ ,  $\rho$ , and  $c$ , except as indicated;  $\rho$  = electrical volume resistivity; unit of  $c = 10^{-6}$  cgsu =  $10^{-6}$  gauss $^{-1}$ ;  $H = 1000$  cgsu = 1 kilogauss;  $R = 10^{-2}$  cgsu =  $10^{-11}$  volt-cm/ampere-gauss;  $t_0 = 10^{-14}$  sec;  $\rho = 10^4$  cgsu =  $10^{-5}$  ohm-cm.

$H$	$\rho$	$R/\rho$	$c$	$t_0$
Ag, Silver				
5 to 7*	0.15†	— 0.59†	— 0.206	— 2.3
5 to 7	(2)	— 0.44	— 0.44	— 5.0
Bi,† Bismuth (37)				
0.80	14.1	— 109	— 109	— 1232
2.45	15.4	— 64.9	— 65	— 734
6.15	17.7	— 44.3	— 44.2	— 500
9.75	20.5	— 31.2	— 31.2	— 352
11.10	21.1	— 29.1	— 29.2	— 330
12.85	22.5	— 26.3	— 26.3	— 298
7.70*	11†	— 92†	— 74	— 840
0.1	(2)	— 72.2	— 72.2	— 820
C, Graphite (37)				
2.60	9.95	— 6.15	— 6.15	— 69.4
4.20	10.95	— 6.05	— 6.05	— 68.4
6.55	13.8	— 5.51	— 5.52	— 62.4
8.40	16.5	— 4.91	— 4.90	— 55.4
9.90	19.4	— 4.59	— 4.60	— 52.0
11.30	21.8	— 4.34	— 4.32	— 48.8
4.6*	45†	— 1.5†	— 0.574	— 6.5
Sb, Antimony				
4*	3.7†	+ 5.2†	+ 3.91	+ 44.2
1.8	(2)	+ 3.6	+ 3.6	+ 40.7
Te, Tellurium (71)				
1 to 9	15000†	+ 3.5†	+ 1.48	+ 16.6
W, Tungsten (71)				
4	0.62†	+ 0.19†	+ 0.156	+ 1.8

TABLE 8.—(Continued)

$H$	$\rho$ †	$R/c$	$c$	$t_0$
Cu,† Copper (37)				
5 to 15	0.17	0.156	— 0.273	— 3.1
Ni, Nickel (17)				
1	1.0	1.81	— 0.83	— 9.4
2		1.36	— 1.07	— 12.1
3		1.38	— 1.08	— 12.2
4		1.44	— 1.09	— 12.3
5		1.45	— 1.10	— 12.4
6		1.54	— 1.08	— 12.2
7		1.39	— 1.02	— 11.5
8		1.35	— 0.94	— 10.6
9		1.36	— 0.84	— 9.4
Zn,† Zinc (37)				
10 to 17	0.57	0.569	+ 0.117	+ 1.32

\* Data on this line are from (71).

† Not for same specimen as  $c$ .

‡ The above values of  $t_0$  for Bi, Cu, and Zn are twice those given by Heaps (37). He computed  $t_0$  from the relation  $c = et_0/m$ , while the above values are calculated from the Adams (1, 2) equation  $c = et_0/2m$ .

TABLE 9.—ETTINGSHAUSEN EFFECT ( $P$ )

$P = A \times 10^{-n}$ ;  $t$  = temperature, in °C;  $t_R$  denotes room temperature; unit of  $H = 1000$  cgsu = 1 kilogauss;  $P = 1$  cgsu = 0.1°C-cm/ampere-gauss.

	$t$	$H$	$A$	$n$	Lit.
Ag.....	$t_R$	*	— 1.65	9	(74, 75)
Al.....	$t_R$	*	+ 1.06	9	(74, 75)
As.....	20	4 to 8	+ 1.75	7	(46)
Au.....	25	9.3	— 1.1	9	(34)
	55	9.3	— 0.6	9	(34)
Bi.....	15	4.71	+ 5.8	5	(22)
	14	10.00	+ 10	5	(5)
	18	6.29	+ 5.16	5	(79)
	18	6.29	+ 5.81	5	(79)
	44	0.3 to 1.2	+ 3.31	5	(62)
	23	3 to 14	+ 7.34	5	(68)
C.....	90	10.27	+ 5	6	(79, 80)
C†.....	17	5.46	— 59.8	6	(28)
	90	5.46	— 54.6	6	(28)
Cd.....	$t_R$	*	— 2.87	9	(74, 75)
Co.....	24	4.4	+ 9	9	(79, 80)
	$t_R$	*	+ 21.6	9	(74, 75)
	25	9.3	+ 8.7	8	(34)
	45	9.3	+ 10.6	8	(34)
Cu.....	$t_R$	*	— 1.6	9	(74, 75)
Fe.....	18	6.29	— 57	9	(79)
	12.2	5.00	— 49.2	9	(35)
	83.9	5.00	— 61.2	9	(35)
	$t_R$	*	— 42.6	9	(74, 75)
Steel....	20	*	— 67	9	(79, 80)
Ni.....	18	10.62	+ 28	9	(80)
	18	6.29	+ 176	9	(79)
	$t_R$	*	+ 30.3	9	(74, 7)
	37.5	9.3	+ 79.2	9	(34)
	57.5	9.3	+ 107	9	(34)
	77.5	9.3	+ 142	9	(34)
Pd.....	25	9.3	+ 17.3	9	(34)
	45	9.3	+ 19.1	9	(34)
	65	9.3	+ 22.5	9	(34)
Sb.....	18	*	+ 1.94	6	(79)
	20	9.13	+ 2	6	(5)
Si.....	18.7	6.15	+ 2.65	3	(28)
	89.7	6.15	+ 1.72	3	(28)
	60	*	< + 3	6	(13)



TABLE 9.—(Continued)

	<i>t</i>	<i>H</i>	<i>A</i>	<i>n</i>	Lit.
Te.....	65	5.5	+ 0.14	3	(47)
	65	5.5	+ 0.29	3	(47)
	13	1 to 15	+ 7.19	5	(77)
	27	1 to 15	+ 10.45	5	(77)
	79	1 to 15	+ 25.6	5	(77)
	124	1 to 15	+ 36.1	5	(77)
Zn.....	<i>t<sub>R</sub></i>	*	- 2.67	9	(74, 75)
		Heusler alloy			
	<i>t<sub>R</sub></i>	*	< 3	8	(81)
		Molybdenite			
	18.1	5.46	+ 27.7	3	(28)
	91.3	5.46	+ 6.98	3	(28)

\* Magnetic field not stated by observer. † Graphite.

TABLE 10.—NERNST EFFECT (*Q*): ELEMENTARY SUBSTANCES

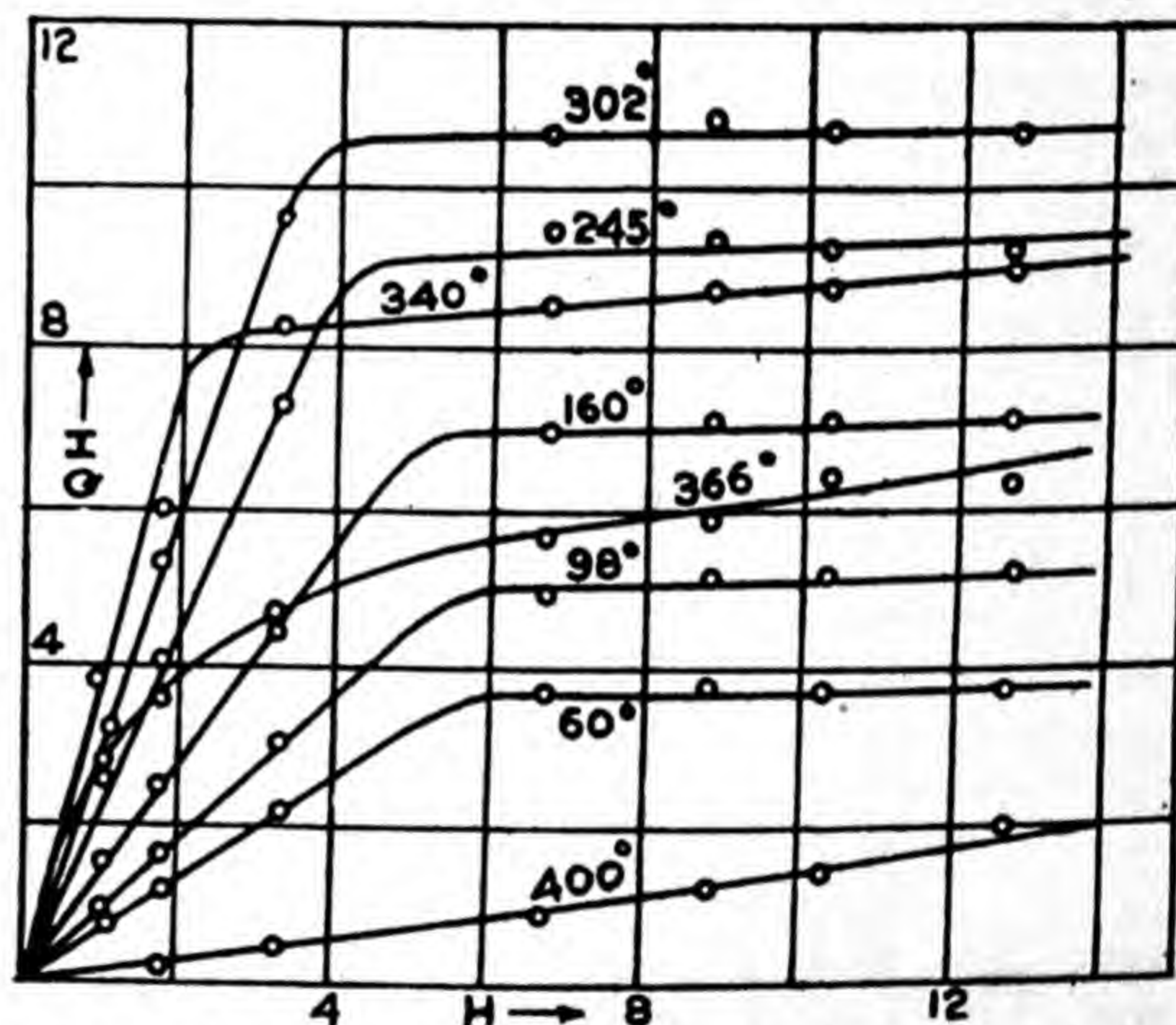
$Q = A \times 10^{-n}$ ; *t* = temperature, in °C; *t<sub>R</sub>* denotes room temperature; unit of *H* = 1000 cgs = 1 kilogauss;  $Q = 1$  cgs =  $10^{-8}$  volt/gauss-°C.

	<i>t</i>	<i>H</i>	<i>A</i>	<i>n</i>	Lit.
Ag.....	18	*	- 43	5	(79, 80)
		*	- 18	5	(74, 75)
Al.....	40	22.7	+ 39	6	(74, 75)
	55	*	- 20	6	(81)
As.....	20	4 to 8	+225	5	(46)
Au.....	25	9.3	-181	6	(34)
	55	9.3	-181	6	(34)
Bi†.....	18	10.57	+275	3	(79)
	27.5	9.92	+136	3	(47)
	42	10.00	+184	3	(5)
	57	2.50	+132	3	(52)
Cd.....		*	- 12	5	(74, 75)
Ce.....	60	17.5	+ 10	5	(68)
Co†.....	18	6.29	+ 20	4	(79)
	27	10.0	+ 18	4	(68)
	57	2.10	+ 25.4	4	(52)
	60	17.5	+ 20.0	4	(68)
		*	+ 7.8	4	(74, 75)
	25	9.3	+ 19.0	4	(34)
	45	9.3	+ 21.7	4	(34)
Cu.....	18	*	- 27	5	(80)
	43.0	13.5	- 16.7	5	(74, 75)
	57	13.3	- 9.0	5	(52)
Fe.....	57	10.1	-156	5	(52)
	48	10.8	- 87	5	(14)
	55	6.29	-105	5	(79)
	55	*	-166†	5	(80)
	31	5.55	- 86.0	5	(35)
	60	5.55	- 98.0	5	(35)
	60	17.5	- 81.0	5	(68)
	48.6	14.8	-106	5	(74, 75)
In.....	60	17.5	+ 32	6	(68)
Ir.....	18	*	- 5	6	(80)
	18	*	> - 2	6	(80)
Li.....	60	17.5	+160	6	(68)
Mn.....		*	+ 15	6	(81)
Mo.....	60	17.5	-172	6	(68)
Ni§.....	55	10.62	+ 13	4	(79)
	55	6.29	+ 35.5	4	(79)
	27	2.0	+ 52.5	4	(68)
	37	1.70	+ 38	4	(50)
	43	4.20	+ 29.5	4	(74, 75)
	37.5	9.3	+ 24.8	4	(34)

TABLE 10.—(Continued)

	<i>t</i>	<i>H</i>	<i>A</i>	<i>n</i>	Lit.
Ni§.—	57.5	9.3	+ 29.2	4	(34)
(Cont'd)	77.5	9.3	+ 35.2	4	(34)
Pb.....	57	*	- 5	6	(52)
Pd.....	18	*	+127	6	(80)
	18	*	+ 51	6	(80)
	25	9.3	+327	6	(34)
	45	9.3	+326	6	(34)
	65	9.3	+334	6	(34)
Sb.....	18	*	+176	4	(79)
	44	9.13	+147	4	(5)
	57	1.7	+ 88.7	4	(52)
Si.....	47.4	5.80	+ 33.3	3	(28)
	50	10 to 20	+ 20	3	(13)
	50	10 to 20	+ 11.3	3	(13)
Sn.....	57	*	- 4(?)	6	(52)
Ta.....	60	17.5	+ 98	6	(68)
Te.....	33	3.00	+ 36	2	(47)
	45.8	4.34	+ 28.7	2	(77)
	204	4.33	+ 26.8	2	(77)
Tl.....	60	17.5	- 37	6	(68)
W.....	60	17.5	-100	5	(68)
Zn.....	46.4	13.5	- 73	6	(74, 75)
	57	13.8	- 54	6	(52)
	18	*	-240	6	(80)

\* Magnetic field not stated by observer. † See also Table 12. ‡ Steel. § See also Fig. 6.

FIG. 6.—Nernst effect (*Q*) in nickel (§§). Unit of *QH* is undetermined, of *H* = 1 kilogauss; temperatures are °C; see also Tables 10, 12.TABLE 11.—NERNST EFFECT (*Q*): ALLOYS

$Q = A \times 10^{-n}$ ; *C*<sub>2</sub> = concentration of constituent 2; *t* = temperature, in °C. Unit of *C*<sub>2</sub> = 1 % by weight; *H* = 1000 cgs = 1 kilogauss;  $Q = 1$  cgs =  $10^{-8}$  volt/gauss-°C.

	<i>C</i> <sub>2</sub>	<i>A</i>	<i>n</i>		<i>C</i> <sub>2</sub>	<i>A</i>	<i>n</i>
(1) Fe, Iron	0	- 9.75	4	(1) Ni,	0	+ 34.8	4
	1.07	- 4.21	4	Nickel	5	+118	4
(2) Ni,	1.93	- 3.06	4		7.5	+147	4
Nickel (§§)	7.05	+ 19.03	4		10	+207	4
	10.20	+ 38.0	4	(2) Cu,	15	+256	4
	13.11	+ 49.5	4	Copper (§§)	25	+350	4
	56.0	+ 1.33	4		30	+174	4
					35	+ 9.7	4
					50	+ 1.7	4



TABLE 11.—(Continued)

Heusler Alloy (81)				Nichrome (67)			
25Mn + 15Al + 60Cu				<i>t</i>	<i>H</i>	<i>A</i>	<i>n</i>
55	3.40	+ 57	5	43	2.50	+708	4
55	5.10	+ 48	5				
Monel (67)				Steel (79)			
68Ni + 29.5Cu + 1.5Fe + 1Mn				55	*	-166	5
60	1.50	+323	3				

\* Value of *H* is not stated.TABLE 12.—NERNST EFFECT (*Q*): VARIATION WITH TEMPERATURE  
Unit of *Q* = 0.001 cgs m = 10<sup>-11</sup> volt/gauss-°C; of *H* = 1 kilogauss; *t* = temperature, °C

<i>t</i>	Ni*		Co		Bi (78); <i>H</i> = 6	
	<i>Q</i> (66)				<i>t</i>	<i>Q</i>
27	+ 5.25	+ 1.80			-119	+900
77	+ 7.25	+ 2.15			- 30.5	+380
127	+ 9.75	+ 2.70			+ 10.0	+173
177	+13	+ 3.30			+ 62.0	+ 46
227	+16.7	+ 4				
277	+21.3	+ 4.85				
327	+27.0	+ 5.70				
377	+34.0	+ 6.75				
427	+ 2	+ 7.80				
477		+ 8.90				
527		+10				

\* See also Fig. 6.

TABLE 13.—RIGHI-LEDUC EFFECT (*S*): ELEMENTARY SUBSTANCES  
Unit of *H* = 1000 cgs m = 1 kilogauss; *S* = 10<sup>-7</sup> cgs m = 10<sup>-7</sup> gauss<sup>-1</sup>; *t* = temperature, °C

	<i>t</i>	<i>H</i>	<i>S</i>	Lit.
Ag.....	<i>t<sub>R</sub></i>	*	- 4.04	(80)
		5.2	- 2.7	(74, 75)
Al.....	40	22.7	- 0.63	(74, 75)
As.....	20	4 to 8	+ 4.15	(46)
Au.....	25	9.3	- 3.00	(34)
	55	9.3	- 2.64	(34)
Bi.....	18	3.93	-20.5	(79)
	18	6.29	+17.4	(79)
	34	6.10	-16	(23)
	42	10.00	+11	(5)
	43.3	0.3 to 1.2	-23	(63)
	52	10.90	-40.5	(70)
Cd.....	60.5	12.20	+ 1.1	(70)
		*	+ 0.89	(74, 75)
Co.....	<i>t<sub>R</sub></i>	10.57	+ 1.3	(79)
		*	+ 1.1	(74, 75)
	25	9.3	+ 3.76	(34)
	45	9.3	+ 4.25	(34)
Cu.....	<i>t<sub>R</sub></i>	*	- 1.4	(79)
	<i>t<sub>R</sub></i>	*	- 2.32	(80)
	43.9	21.40	- 2.27	(74, 75)
Fe.....	48	7.30	+ 6.08†	(14)
	44	6.50	+ 4.29	(35)
	60.2	5.50	+ 6.32	(35)
	<i>t<sub>R</sub></i>	6.29	+ 3.9	(79)
	<i>t<sub>R</sub></i>	*	+ 6.87†	(80)
	48.6	11.30	+ 5.54	(74, 75)
	56.9	11.90	+ 3.92§	(70)
Ir.....	<i>t<sub>R</sub></i>	*	+ 0.55	(80)
	<i>t<sub>R</sub></i>	*	+ 0.41	(80)

TABLE 13.—(Continued)

	<i>t</i>	<i>H</i>	<i>S</i>	Lit.
Mo.....	57.5	12.30	+ 1.75	(70)
Ni.....	<i>t<sub>R</sub></i>	10.62	- 2.0§	(79)
	<i>t<sub>R</sub></i>	6.29	- 5.5§	(79)
	61	10.88	- 6.15	(70)
	61.5	8.50	- 5.30	(74, 75)
	37.5	9.3	- 5.28	(34)
	57.5	9.3	- 4.93	(34)
	77.5	9.3	- 4.46	(34)
Pd.....	<i>t<sub>R</sub></i>	*	- 0.33	(80)
	<i>t<sub>R</sub></i>	*	- 0.18	(80)
	25	9.3	- 0.487	(34)
	45	9.3	- 0.414	(34)
	65	9.3	- 0.380	(34)
Pt.....	<i>t<sub>R</sub></i>	*	- 0.21	(80)
Sb.....	18	*	+20.1	(79)
	20	9.13	+20	(5)
	56.7	11.00	+26.2	(70)
Si.....	47.8	5.00	+ 2.5	(28)
	47.4	5.80	+ 2.97	(28)
Te.....	34	5.2	+40	(47)
	114	7.75	+62	(77)
W.....	58.6	10.90	+ 1.5	(70)
Zn.....	46.4	21.10	+ 1.06	(74, 75)
	<i>t<sub>R</sub></i>	*	+ 1.29	(80)
	58.5	10.9	+ 1.24	(70)

\* Magnetic field not stated by observer. † Soft. ‡ Steel. § Electrolytic.

TABLE 14.—RIGHI-LEDUC EFFECT (*S*): ALLOYS  
Unit of *C*<sub>1</sub> = 1 % of constituent 1; *S* = 10<sup>-7</sup> cgs m = 10<sup>-7</sup> gauss<sup>-1</sup>; of *H* = 1 kilogauss

	<i>C</i> <sub>1</sub>	<i>S</i>		<i>C</i> <sub>1</sub>	<i>S</i>
(1) Bi, Bismuth	0	+26.2	(1) Sb, Antimony	0	+ 1.24
	10	+13.2		16	+ 0.660
	20	+ 9.5		30	+ 0.840
(2) Sb, Antimony	30	+ 0.95	(2) Zn, Zinc (70);	40	+ 0.677
(70); <i>H</i> = 11	39	- 6.0	<i>H</i> = 11	50	+ 0.850
	50	-15.4		60	+ 0.908
	60	-19.5		70	+ 2.09
	70	-35.4		80	+ 2.75
	91	-37.5		84	+ 3.20
	100	-40.5		90	+ 4.27
				100	+26.2
Steel, <i>t</i> = <i>t<sub>R</sub></i> , <i>H</i> = *		+ 6.87	Nichrome, <i>t</i> =		+ 3.88†
			59.3°C		

\* Value not stated by observer.

† *H* = 10.8 kilogauss.TABLE 15.—INCREASE ( $\Delta r$ ) PRODUCED IN ELECTRIC RESISTANCE (*r*) BY MAGNETIC FIELD (*H*): NON-MAGNETIC MATERIALS

$\Delta r/r = CH^2$ ;  $C = A \times 10^{-10}$ ; || denotes that *H* is parallel to the current; for unmarked values, *H* is perpendicular to the current; unit of *C* = 1 cgs m = 1 gauss<sup>-2</sup>; of *H* = 1 cgs m = 1 gauss; *t* = temperature, °C.

Ag, Silver*				Au.—(Continued)			
<i>t</i>	<i>A</i>	<i>n</i>	Lit.	<i>t</i>	<i>A</i>	<i>n</i>	Lit.
22	25	14	(58, 60)	-253	17†	11	(56)
22	37	14	(29)	23	32	14	(36)
23	18	14	(58, 60)	22	12	14	(53)
Au, Gold*							
23	36	14	(29, 36, 58)				
100	30	14	(53)				
24	22	14	(53)				

Bi, Bismuth; cf. Tables 16, 17  
*t<sub>R</sub>* | 75|| | 10 | (5)



TABLE 15.—(Continued)

C, Carbon†			
<i>t</i>	<i>A</i>	<i>n</i>	Lit.
<i>t<sub>R</sub></i>	44§	14	(58)
16	78¶	12	(43)
−186	225¶	12	(43)
Cd, Cadmium			
22	27	13	(29, 36, 59)
98	99	14	(43)
55	160	14	(43)
16	265	14	(43)
−186	51†	12	(43)
−253	76†	10	(57)
17	177	14	(36)
−253	50  †	10	(57)
Cu, Copper**			
22	27	14	(29, 58, 60)
100	55	14	(53)
21	27	14	(53)
−253	14†	10	(56)
−258	10†	10	(56)
<i>t<sub>R</sub></i>	33	14	(58)
23	22	14	(60)
21	35	14	(53)
100	65	14	(53)
Hg, Mercury			
20	54	14	(58)
−253	15	12	(57)
−258.5	60	12	(57)
Pb, Lead			
22	52	15	(29)
−253	55†	12	(57)
−253	55  †	12	(57)
Pd, Palladium			
25	11	14	(29)
−253	15†	12	(56)
Pt, Platinum			
<i>t<sub>R</sub></i>	53.7	15	(58)
22	39	15	(29)
Sb, Antimony; see Table 17			
Si, Silicon			
<i>t<sub>R</sub></i>	26	13	(42)
Sn, Tin			
22	23	14	(29, 58)
−253	92†	11	(57)
<i>t<sub>R</sub></i>	18	14	(58)
−253	92  †	11	(57)
Ta, Tantalum			
25	30	15	(29)
Te, Tellurium			
<i>t<sub>R</sub></i>	1 to 10	11	(7, 9, 36, 45, 48)
24	277	13	(36)
Zn, Zinc*			
<i>t</i>	<i>A</i>	<i>n</i>	Lit.
<i>t<sub>R</sub></i>	8	13	(29, 58)
20	14	13	(36)
55	54	14	(43)
18	85	14	(43)
−186	17	12	(43)
<i>t<sub>R</sub></i>	60	14	(58)
20	82	14	(36)
FeS <sub>2</sub> , Pyrite			
22	< 2	13	(36)
MoS <sub>2</sub> , Molybdenite			
22	− 37	13	(36)
PbS, Galena			
22	2††	12	(36)
22	236	14	(36)
Pt, Ir, Platinum-iridium			
100	+ 10	14	(53)
−183	− 25	15	(53)
Cu, Ni, Advance			
23	− 12	14	(60)
23	− 12	14	(60)
Cu, Ni, Mn, Constantan††			
79	+ 32	15	(53)
16.7	− 23	14	(53)
−183	− 51	12	(53)
84	− 13	14	(53)
19	− 26	14	(53)
−183	− 49	12	(53)
Cu, Ni, Mn, Eureka††			
100	− 8	14	(53)
26	− 14	14	(53)
100	− 8	14	(53)
25	− 18	14	(53)
Cu, Ni, Mn, Manganin††			
23	− 90	15	(60)
100	− 35	14	(53)
20	− 55	15	(53)
−183	− 27	13	(53)
23	− 87	15	(60)
100	− 3	14	(53)
5	− 6	14	(53)
−183	− 24	13	(53)
Cu, Ni, Mn, Platinoid††			
24	− 9	14	(53)
100	− 2	14	(53)
25	− 87	15	(53)
Cu, Sn, P, Phosphor bronze			
27.5	− 5	15	(53)
100	+ 1	13	(53)
−183	+ 5	14	(53)
Ni, Cr, Mn, Fe, Nichrome††			
28.5	− 114	14	(53)
27	+ 18	14	(53)

\* Brown (12.1) found  $\Delta r/r \pm < 0.0001$  for  $H \geq 10^4$ , whether || or  $\perp$ . For Zn he found same values for single crystal. † *A* varies with *H*; for Cd,  $H = 7600$ ; for Pb and Sn,  $H = 11\,000$ . ‡ See also Table 18. §  $H = 22\,000$ . ¶  $H = 3\,300$ ; for graphite at  $15.5^\circ\text{C}$ ,  $A = 77.5$ . \*\* Brown (12.1) found  $\Delta r/r = 0.0004$  for  $H = 10^4$  and ||;  $\Delta r/r \pm < 0.0001$  for  $H \geq 8000$  and  $\perp$ . †† Ranges from 0.05 to 4.5. ‡‡ Constantan = 55.86 Cu, 43.33 Ni, 0.66 Mn, trace Fe; eureka = 53.53 Cu, 44.63 Ni, 0.96 Mn, 0.71 Fe; manganin = 82.3 Cu, 4.0 Ni, 12.3 Mn, 0.08 Fe; platinoid = 54.21 Cu, 43.91 Ni, 1.02 Mn, 0.52 Fe; nichrome = 15.57 Cr, 58.31 Ni, 3.19 Mn, 22.42 Fe.

TABLE 16.—INCREASE PRODUCED IN ELECTRICAL RESISTANCE (*r*) OF BISMUTH BY TRANSVERSE MAGNETIC FIELD (*H*)

Tabular values are  $A = \frac{r - r_0}{r_0}$ ,  $r_0$  = resistance when field = 0; *r* and  $r_0$  refer to the same temperature; *H* is perpendicular to direction of current; see also Tables 15, 17; unit of *H* = 1000 cgs = 1 kilogauss.

Wire of Electrolytic Bismuth (10)					
$\begin{array}{c} t \\ H \end{array}$	183°	100°	60°	18°	0°C
4	0.017	0.03	0.05	0.12	0.18
8	0.045	0.10	0.17	0.32	0.43
12	0.072	0.18	0.30	0.52	0.71
16	0.095	0.27	0.43	0.79	1.02
20	0.13	0.37	0.58	1.04	1.33
25	0.17	0.48	0.78	1.33	1.73
30	0.21	0.61	0.97	1.65	2.17
35	0.26	0.73	1.13	2.01	2.62

$\begin{array}{c} t \\ H \end{array}$	−37°	−100°	−135°	−192°C
4	0.25	0.71	1.25	4.80
8	0.70	1.85	3.80	13.7
12	1.20	3.04	6.83	26.0
16	1.70	4.87	10.6	37.0
20	2.18	6.71	17.2	48.5
25	2.98	9.57	21.1	62.7
30	3.77	13.0	29.3	78.2
35	4.62	16.4	32.9	87.7

Wire of Electrolytic Bismuth (56)				
$\begin{array}{c} t \\ H \end{array}$	17°	−103°	−133.5°	−183.5°C
2.76	0.078	0.506	0.884	2.65
5.54	0.211	1.328	2.236	7.60
7.37	0.313	1.893	3.321	12.21
9.20	0.414	2.576	4.574	17.37
11.85	0.557	3.649	6.745	26.76
13.60	0.652	4.626	8.231	34.93
15.67	0.767	5.500	10.37	43.74
17.08		6.268	12.04	50.95

$\begin{array}{c} t \\ H \end{array}$	−201°	−252.7°	−258°C
2.76	3.36	18.5	
5.54	10.43	54.8	65.3
7.37	16.79	92.0	105.5
9.20	23.75	129.7	152.9
11.85	37.35	190.6	220.8
13.60	47.9	239.5	271.0
15.67	61.6	291.3	333.5
17.08	71.4	333.1	379

Bismuth Plate (26)									
100°		11.5°		−23°		−90°		−182°C	
H	A	H	A	H	A	H	A	H	A
2.2	0.009	1.05	0.009	1.06	0.015	1.02	0.035	2.05	0.359
3.95	0.026	2.06	0.030	2.14	0.052	2.14	0.125	3.73	0.902
4.83	0.040	3.06	0.58	3.11	0.097	3.10	0.224	4.74	1.271
6.10	0.058	4.43	0.104	3.79	0.132	3.76	0.299	6.00	1.757
		6.03	0.166	4.41	0.166	4.15	0.346		
				5.25	0.215	5.20	0.477		
				6.05	0.265	6.11	0.596		



TABLE 16.—(Continued)  
Bismuth Crystal (48);  $H \perp$  axis

$H$	Current $\parallel$ axis			Current $\perp$ axis		
	22.5°	-79°	-186°C	14°	-79°	-186°C
2.12	0.050	0.225	0.335	0.039	0.096	0.061
3.12	0.092	0.377	0.442	0.073	0.142	0.097
3.50	0.121	0.431	0.474	0.086	0.157	0.106
4.98	0.198	0.621	0.565	0.143	0.215	0.114

TABLE 17.—ELECTRICAL RESISTANCE ( $r$ ) OF ANTIMONY AND OF BISMUTH IN TRANSVERSE MAGNETIC FIELD ( $H$ ) (30)

$r/r_0 = a\{1 - b(c \mp dH)\}$ ;  $r/r_{00} = \alpha\{1 - \beta(\gamma - \delta H)\}$  where  $r_0$  = resistance at  $t^\circ\text{C}$  when  $H = 0$ ;  $r_{00}$  = resistance at  $0^\circ\text{C}$  when  $H = 0$ ; unit of  $H = 1000$  cgs = 1 kilogauss.

Bismuth\* (compressed powder)

$t$	$\alpha$	$\beta$	$\gamma$	$\delta$
-183	102.34	0.998	85.99	2.04
-201	134.06	0.999	86.64	2.166
-253	75.74	1.005	82.97	5.09
-258	68.4	1.005	82.03	5.45

Antimony† (crystal)

$t$	$a$	$b$	$c$	$d$
18	1.519†	0.336	91.13	1.125
-188	2.742†	0.656	77.95	2.022
18	1.167§	0.1453	79.95	2.665
-188	10.08§	0.0957	80.88	1.069

\* See also Tables 15, 16. † Current perpendicular to axis. ‡ Field parallel to axis. § Field perpendicular to axis.

TABLE 18.—ELECTRICAL RESISTANCE ( $r$ ) OF GRAPHITE IN TRANSVERSE MAGNETIC FIELD ( $H$ ) (59)

Current perpendicular to axis of crystal;  $r/r_{00} = a + bH^{1.745}$ ;  $r_{00}$  = resistance at  $0^\circ\text{C}$  when  $H = 0$ ;  $A = \frac{r - r_0}{r_0}$ ;  $r_0$  = resistance at  $t^\circ\text{C}$  when  $H = 0$ ; unit of  $H = 1000$  cgs = 1 kilogauss; see also Table 15.

No.	$a^*$	$b^*$	$H$	$A^\dagger$	$A^\ddagger$	$H$	$A^\dagger$	$A^\ddagger$
I.....	1.01	0.0171	5.73	0.40	0.008	26.15	5.91	0.115
II.....	1.01	0.0205	9.60	1.04	0.020	29.75	7.36	0.148
III.....	1.004	0.0160	14.78	2.16	0.040	33.98	9.28	0.172
IV.....	1.014	0.0188	20.3	3.91	0.070	35.2	9.89	0.189
V.....	1.02	0.0214	21.9	4.56	0.083	36.4	10.5	0.194
Temperature = $18^\circ\text{C}$			23.2	4.75	0.092	Temperature = $20^\circ\text{C}$		

\* Cleavage plane normal to  $H$ . † Axis of crystal parallel to  $H$ . ‡ Axis of crystal normal to  $H$ .

TABLE 19.—INCREASE ( $\Delta r$ ) PRODUCED IN ELECTRICAL RESISTANCE ( $r$ ) BY TRANSVERSE MAGNETIC FIELD ( $H$ ): MAGNETIC MATERIALS

$\frac{\Delta r}{r} = 0.0001A$ ; for effect of longitudinal field, see Table 20; unit of  $H = 1000$  cgs = 1 kilogauss;  $t$  = temperature,  $^\circ\text{C}$

Co, Cobalt (6)				Fe, Iron (12.1)			
$H$	$A$	$H$	$A$	$H$	$A$	$H$	$A$
2.4	-3.64	10.3	-47.44	4	$\pm < 1$	8	$\pm < 1$
5.1	-9.28	11.7	-60.82				
6.0	-17.56	13.8	-64.40				
8.5	-24.58	16.16	-67.96				
(29)				(29)			
3.8	-5.89	11.4	-56.9	0.22	-0.387	3.40	-0.851
8.2	-42.3	16.16	-69.9	0.47	-0.381	8.44	-1.630
				1.33	-0.481	11.48	-3.893

TABLE 19.—(Continued)  
Fe (9, 56)

$t =$	15°	-252.8°	-258.6°C
$H$	$A$		
0.99	+2.8		-1.7
1.50	+3.8	-2.0	
2.52	+5.7	-2.9	-2.6*
3.75	+6.0	-2.7	-3.1
4.94	+5.4	-2.2	-2.4
6.11	+3.2	-0.9	-1.4
7.26	+0.6	+0.7	+0.3
8.25	-2.1†	+2.6	+2.6
9.065	-4.7	+3.6	+3.6
9.75		+4.6	+4.7
10.27	-9.1	+5.2	+5.4

\*  $H = 2.50$ .

†  $H = 8.26$ .

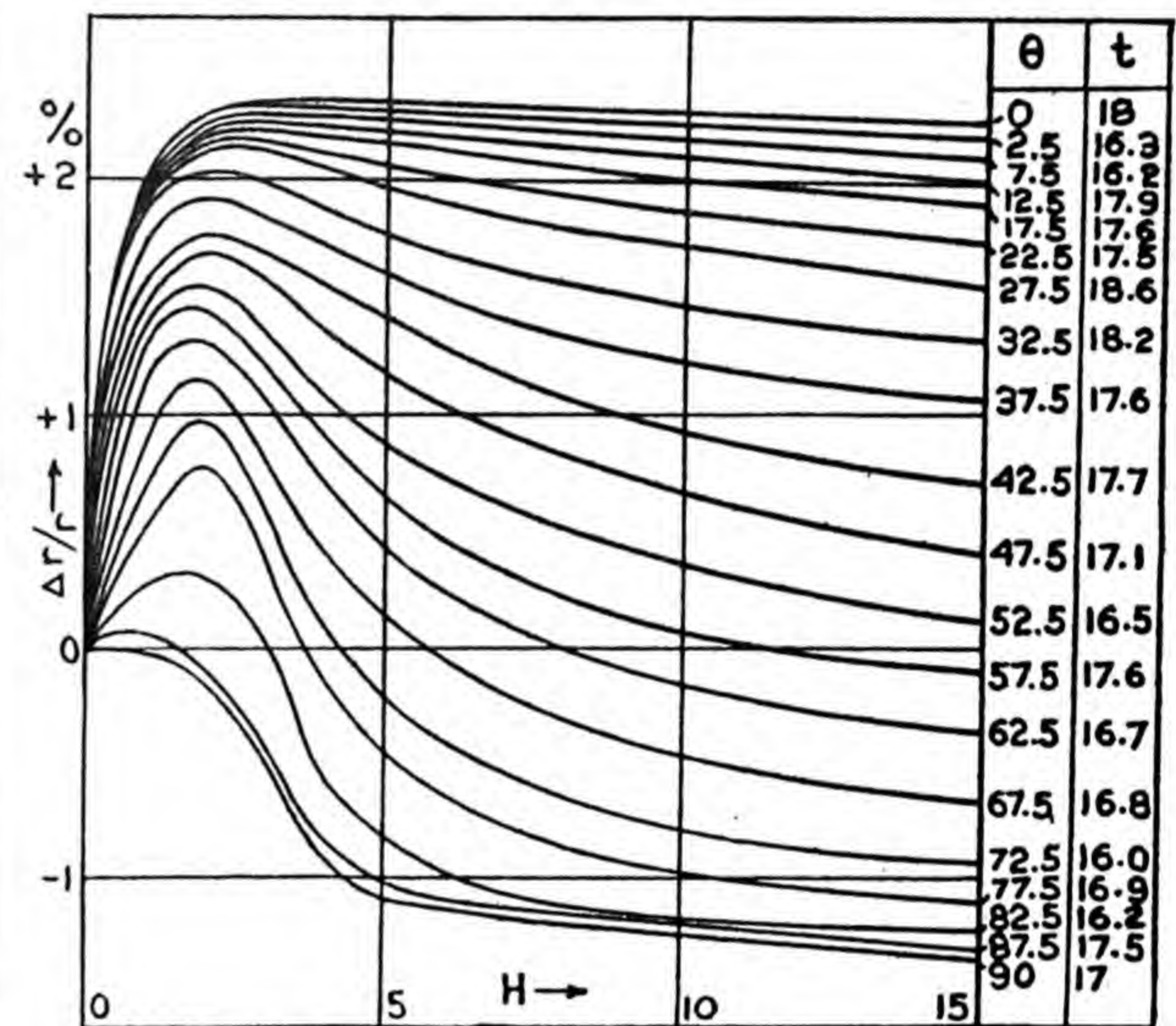


FIG. 7.—Effect of magnetic field ( $H$ ) upon electrical resistivity ( $r$ ) of nickel (49). Unit of  $H = 1$  kilogauss;  $\theta$  = angle direction of current makes with  $H$ ;  $t$  = centigrade temperature; see also Tables 19, 20.

Ni, Nickel† (10)

$t =$	182°	100°	18°	0°	-75°	-190°C
$H$	$A$					
1	4	96	7	7	23	20
2	-7	72	3	3	16	17
3	-60	-14	-36	-34	-5	0
4	-115	-70	-72	-60	-15	-17
6	-153	-102	-83	-70	-20	-19
8	-166	-115	-90	-76	-23	-19
10	-176	-123	-95	-82	-27	-18
12	-185	-130	-100	-87	-30	-18
14	-195	-137	-104	-91	-32	-18
16	-205	-144	-109	-94	-35	-17
18	-215	-151	-113	-98	-38	-17
20	-225	-159	-117	-103	-41	-16
25	-250	-176	-129	-112	-49	-14
30	-273	-195	-140	-122	-56	-12
35	-298	-213	-150	-132	-63	-10

† See also Fig. 7.



TABLE 19.—(Continued)

Ni, Nickel† (56)

$t =$	17.5°	−183°	−253°	−258.5°C
$H$	$A$			
1.75	5		10	
2.27		20		
2.50	5	30	20	
2.97	0			0
3.75	−20	0	0	
4.95		−55		
5.17	−40			
5.64			−80	−70
6.14		−65		
7.26	−70			
8.25		−95§	−120	−110
9.065	−90		−130	
9.11		−125		
10.27	−110		−150	−130
10.40		−140		

† See also Fig. 7. §  $H = 8.29$ .TABLE 20.—INCREASE ( $\Delta r$ ) PRODUCED IN ELECTRICAL RESISTANCE ( $r$ ) BY A LONGITUDINAL MAGNETIC FIELD ( $H$ ): MAGNETIC MATERIALS $\Delta r/r = 0.0001A$ ; for effect of transverse field, see Table 19; unit of $H = 1000 \text{ cgsm} = 1 \text{ kilogauss}$ 

Fe* (12.1)		Ni.—(Continued)		Norway Iron.—	
$H$	$A$	$H$	$A$	$H$	$A$
10	+20	18°C (39)		(Continued)	
		0.15	+60	1.25	−27.8
		0.30	98	1.50	−28.0
		0.48	120	1.75	−28.0
		0.60	126	2.00	−28.0
		0.90	129	Fe† (38)	
		1.20	130	Room temp.	
		1.50	131	0.20	−15.5
		1.80	131	0.40	−24.5
		Norway Iron (36)		0.60	−29.0
		23°C		0.80	−31.2
		0.25	−15.0	1.00	−31.7
		0.50	−22.5	1.20	−31.9
		0.75	−26.0	1.40	−32.0
		1.00	−27.5	1.60	−32.1

\* Induction = 36 000 cgsm. † See also Fig. 7.  
† Electrolytic iron.TABLE 21.—INCREASE ( $\Delta k$ ) PRODUCED IN THERMAL CONDUCTIVITY ( $k$ ) BY MAGNETIC FIELD ( $H$ ) $\Delta k = k_H - k_0$ ;  $k_H$ ,  $k_0$  = thermal conductivity in field  $H$ , in field = 0; as applied to  $H$ ,  $\perp$  [||] indicate that  $H$  is perpendicular [parallel] to direction of flow of heat;  $\Delta k/k = 0.001A$ ; unit of  $H = 1 \text{ kilogauss}$ .

	$H$	$A$	Lit.
Ag.....	10	$\pm < 0.4$	(12.1)
	4 & 8 $\perp$	$\pm < 0.4$	(12.1)
Au.....	10	$\pm < 0.4$	(12.1)
	4 & 8 $\perp$	$\pm < 0.4$	(12.1)
Bi*.....	3.5 $\perp$	$-\infty$	(11)
	6.0 $\perp$	−58	(24)
	7.8 $\perp$	−57	(44)
	9.0 $\perp$	−21 to −52	(19)
	5.4 $\perp$	−32	(76)

TABLE 21.—(Continued)

	$H$	$A$	Lit.
Cu.....	10	−2.3	(12.1)
	8	−2.1	(12.1)
	4 & 8 $\perp$	$\pm < 0.4$	(12.1)
Fe.....	10  †	−11.4	(12.1)
	8 $\perp$	$\pm < 0.4$	(12.1)
	4 $\perp$	−4	(12.1)
	16  †	−105	(11)
	7.8 $\perp$	−10	(11)
	7.5 $\perp$	−33¶	(11)
	1.7  §	−small	(12)
	1.5  §	−small¶	(12)
	0.051	−40¶	(12)
Ni.....	1.2§	**	(61)
Te.....	6.6 $\perp$	−190	(77)
	4.7 $\perp$	−100	(47)
Zn††.....	10	$\pm < 0.4$	(12.1)
	8 $\perp$	$\pm < 0.4$	(12.1)

\* Crystalline, but not single crystal.  $k \perp$  axis of crystal  
 $k \parallel$  axis of crystal = 1.42 if  $H = 0$ ,  
= 1.80 if  $H = 4.9$  (49). † Induction = 36 000 cgsm. ‡ Induction. § Intensity  
of magnetisation. ¶ Steel. \*\*  $k_H, H \parallel$   
 $k_H, H \perp = 1.05$  (61). †† Same for single crystal.

## LITERATURE

(For a key to the periodicals see end of volume)

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## MAGNETO-OPTICS

A. COTTON, R. LUCAS, AND M. CAU

This section is devoted to data pertaining to the rotation of the plane of polarization of light (I) during transmission through materials and along a magnetic field (Faraday effect), and (II) at

reflection from magnetized materials (Kerr effect) (p. 435). Other magneto-optic phenomena are considered elsewhere; consult the index.

## I. ROTATION DURING TRANSMISSION—FARADAY EFFECT

A. COTTON AND R. LUCAS

## CONTENTS

Verdet Constant.	PAGE
Water.....	425
Gases and vapors.....	425
Pure inorganic solids and liquids and miscellaneous materials	426
TiCl <sub>4</sub> .....	426
Pure organic liquids.....	426
Solutions of inorganic substances.....	426
Solutions of organic substances.....	427
In infra-red.....	427
Molecular magnetic rotatory power relative to water.....	428
Specific magnetic rotatory power of solutions.....	431
Dispersion of Verdet constant: Formulae.	
Pure gases.....	432
Pure substances, $V/V_D$ .....	432
Pure organic substances, $V/V_{Hg}$ .....	434
Lag in appearance of Faraday effect.....	434

The *Verdet constant* ( $V$ ) of a substance is  $V = \alpha/(lH \cos \varphi)$ , where  $\alpha$  = angular rotation,  $l$  = length of path through the substance,  $H$  = intensity of magnetic field, and  $\varphi$  = angle between  $l$  and  $H$ . The positive direction of  $\alpha$  is related to that of  $l$  as the rotation of a right-handed screw is related to its advance;  $V$  is positive when  $\alpha$  is in the direction of the Amperian currents which would produce the field  $H$ .  $V_D$  and  $V_{Hg}$  are the values of  $V$  which correspond to the  $D$  lines and to the green mercury line ( $\lambda = 5461 \text{ \AA}$ ), respectively.

The *specific magnetic rotatory power* is  $[\omega] = V/d$ , the *molecular magnetic rotatory power* is  $M[\omega]$ , where  $d$  = density,  $M$  = molecular weight. The ratios of  $[\omega]$  and of  $M[\omega]$  to the corresponding values for water at the same temperature and for the same  $\lambda$ , are called, respectively, the *relative specific* and the *relative molecular* ( $[\Omega]$ ) magnetic rotatory powers with reference to water. If the rotation depends upon the nature and the mass of material, per unit of area traversed, and not upon the closeness of packing of the molecules, then for a mixture  $[\omega]_m = V/\alpha = \tau_1[\omega]_1 + \tau_2[\omega]_2 + \dots$ , where  $\tau_1, \tau_2, \dots$  are the titers of the several constituents. In general, this relation is not exactly satisfied. If  $[\omega]$  for each of the pure constituents is known, it is convenient to express  $[\omega]_m$  in terms of  $\Delta$  defined by  $[\omega]_m = (1 + \Delta)(\tau_1[\omega]_1 + \tau_2[\omega]_2 + \dots)$ . When  $[\omega]_m$  is known for a binary mixture, but  $[\omega]_2$  is not known, it is customary to call the quantity  $[\omega]_2'$ , defined by  $\tau_2[\omega]_2' = [\omega]_m - \tau_1[\omega]_1$ , the *specific magnetic rotatory power* of that constituent; it is preferable to call it the *apparent power* under the stated conditions.

TABLE 1.—VERDET CONSTANT FOR WATER\*

$t$  = temperature, °C;  $\lambda_D = 5893 \text{ \AA}$ . Unit of  $V = 0.01'$  per cm-gauss;  $\lambda = 1 \text{ \AA}$

$t$	$V_D \dagger$	$\lambda$	$V/V_D \dagger \ddagger$	$\lambda$	$V/V_D \dagger$
0	1.311	3 034	4.6270	4 958	1.4520
20	1.308	3 303	3.7337	5 461	1.184§
30	1.306	3 611	2.9908	6 000	0.964
40	1.302	3 962	2.4051	8 000	0.535
60	1.294	4 341	1.9514	10 000	0.337
80	1.282	4 360	1.916§	12 500	0.222
90	1.274	4 678	1.6481		

\*  $\frac{c_1}{n\lambda^2} \left\{ \left( \frac{\lambda^2}{\lambda_1^2 - \lambda^2} \right)^2 + K_1 \right\}$ ;  $\lambda_1 = 1260.4 \text{ \AA}$ ,  $K_1 = 0.7381$  (21).  $V = \frac{c}{\lambda} (n - K\lambda \frac{dn}{d\lambda})$ ;  $K = 77.65$ , for visible spectrum only (14, 23).

†  $V_t = V_{20} \{ 1 - 153(t - 20) \times 10^{-6} - 3.06(t - 20)^2 \times 10^{-6} \}$  if  $3 \geq t \geq 98$ ;  $V_D, 20^\circ = 1.308$  (22).

‡ (21) except as noted.

§ (25).

|| (13).

TABLE 2.—VERDET CONSTANT FOR GASES AND VAPORS

For certain gases (26),  $V = \frac{a}{\lambda} + \frac{b}{\lambda^3}$  if  $0.423\mu \geq \lambda \geq 0.684\mu$ .

For liquefied gases, see Tables 3, 5. Temperature ( $t$ ) in °C;  $\lambda_D = 0.5893\mu$ . Unit of  $V = 10^{-6}$  minute of arc per cm-gauss;  $\lambda = 1\mu = 10^4 \text{ \AA}$ ;  $p = 10^6$  barye =  $0.987A_m$ .

	$t$	$p$	$V_D$	$a$	$b$	Lit.
H*.....	9.5	83.3	456	138.8	45.19	(26)
N.....	ca. 20	ca. 1	6.92			(3)
N.....	14	98.1	549	171.22	52.86	(26)
O*.....	ca. 20	ca. 1	31.39			(3)
O.....	7	98.1	555	272.2	19.15	(26)
N <sub>2</sub> O.....	ca. 20	ca. 1	6.28			(3)
N <sub>2</sub> O.....	10.9	30.9	241	75.85	22.95	(26)
SO <sub>2</sub> .....	20	3.3	38.40			(5)
CO <sub>2</sub> *.....	6.5	1.1	8.61	2.68	0.83	(26)
CS <sub>2</sub> .....	70	0.98	23.49			(5)
C <sub>2</sub> H <sub>4</sub> .....	ca. 20	ca. 1	34.48			(3)
Air.....	ca. 20	ca. 1	6.83			(3)
Air.....	13	98.1	551	191.5	46.19	(26)

\* For dispersion of  $V$  in ultra-violet, see Table 12.



TABLE 3.—VERDET CONSTANT FOR PURE INORGANIC LIQUIDS AND SOLIDS AND FOR MISCELLANEOUS MATERIALS

For values in infra-red, see Table 8; for gases and vapors, see Table 2

Unit of  $V = 0.001'$  per cm-gauss;  $\lambda_D = 5893 \text{ \AA}$ ;  $t$  = temperature,  $^{\circ}\text{C}$ 

	$t$	$V_D$	Lit.
C*	16	12.8	(2)
N <sub>2</sub>	-195.5	4.15	(8)
O <sub>2</sub>	-182.5	7.82	(8)
P†	33	132.6	(2)
S†	114	80.9	(2)
H <sub>2</sub> O†	0	13.11	(22)
HCl§	20	11.60	(25)
HBr	15	34.3	(18)
HI		51.3	(18)
SO <sub>2</sub>	-10	18	(8)
H <sub>2</sub> SO <sub>4</sub>	16	10.5	(4)
H <sub>2</sub> SO <sub>4</sub> ¶	15	10.16	(25)
S <sub>2</sub> Cl <sub>2</sub>	16	41.8	(4)
N <sub>2</sub> O**	-92	5.54	(28)
HNO <sub>3</sub> ††	16	8.76	(4)
PCl <sub>3</sub>	16	27.7	(4)
P <sub>4</sub> S	16	110	(4)
AsCl <sub>3</sub>	16	42.53	(4)
SbCl <sub>3</sub>	16	70.4	(4)
CO <sub>2</sub>	26	2.07	(8)
SiO <sub>2</sub> ††	20	16.64	(7)
SiCl <sub>4</sub>	16	18.9	(4)
TiCl <sub>3</sub>	16	15.21	(4)
TiCl <sub>4</sub>	See Table 4		
SnCl <sub>2</sub>	16	44.0	(4)
PbSiO <sub>3</sub> †	16	77.9	(4)
PbB <sub>2</sub> O <sub>4</sub> ·H <sub>2</sub> O	16	59	(4)
ZnS(β)§§	16	225	(4)
MgAl <sub>2</sub> O <sub>4</sub>	16	21.0	(6)
CaF <sub>2</sub> ¶¶	16	8.83	(4)
NaCl	16	35.85	(4)
Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·10H <sub>2</sub> O	16	17.2	(4)
KCl***	16	28.58	(4)
Amber	19	9.60	(20)
Glass, Jena:†††			
S.179	18	16.1	(6)
O.1143	18	22.0	(6)
O.451	18	31.7	(6)
O.469	18	44.2	(6)
O.500	18	60.8	(6)
S.143	18	88.8	(6)

\* Diamond. † Fused. ‡ See also Table 1. §  $d_{20}^{20} = 0.8240$ . ||  $d_{15} = 1.854 \text{ g cm}^{-3}$ . ¶  $d_{15}^{15} = 1.83840$ . \*\* Liquid at 1 atm. †† Fuming. ‡‡ Quarts; perpendicular to axis; see also p. 343. §§ Zinc blende, sphalerite. ||| Spinel colored with chromium. ¶¶ Fluorite. \*\*\* Sylbite. ††† S.179 = Phosphate crown; O.1143 = barium crown; O.451 = light flint; O.469 and O.500 = heavy flint; S.143 = very heavy flint.

TABLE 4.—VERDET CONSTANT FOR TiCl<sub>4</sub> (29)Unit of  $V = 0.001'$  per cm-gauss;  $\lambda = 1 \text{ \AA}$ ; temperature =  $13.4^{\circ}\text{C}$ 

$\lambda$	$V$	$\lambda$	$V$	$\lambda$	$V$	$\lambda$	$V$	$\lambda$	$V$
4355	54.39	4623	40.54	4723	36.89	5086	27.05*	5601	18.30
4358	56.33*	4688	38.43	4805	34.68*	5097	26.43	5780	16.18*
4436	49.27	4694	37.78	4840	33.25	5245	23.43	5956	14.71
4495	46.87	4722	37.82*	4889	31.70	5461	20.23*	6452	10.83

\* Temperature =  $17.9^{\circ}\text{C}$ .

TABLE 5.—VERDET CONSTANT FOR PURE ORGANIC LIQUIDS

For values in infra-red, see Table 8; for relative molecular magnetic rotatory power, see Table 9. Temperature ( $t$ ) in  $^{\circ}\text{C}$   
Unit of  $V = 0.001'$  per cm-gauss;  $\lambda_D = 5893 \text{ \AA}$ 

	Liquid	$t$	$V_D$	Lit.
CS <sub>2</sub> *	Carbon disulfide.....	0	43.41	(4)
		15.6	42.4	(25)
		18.0	43.0	(8)
		20	42.26†	(5)
		34	41.1	(25)
CCl <sub>4</sub>	Carbon tetrachloride.....	15	16.03	(25)
CH <sub>3</sub> Cl	Methyl chloride.....	18	12.9	(8)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Acetic acid.....	15.2	10.35	(25)
		32.0	10.19	(25)
C <sub>2</sub> H <sub>5</sub> O	Ethyl alcohol.....	25.0	11.12†	(31)
C <sub>3</sub> H <sub>6</sub> O	Acetone.....	15.1	11.09	(25)
		31.5	10.86	(25)
C <sub>3</sub> H <sub>7</sub> O	<i>n</i> -Propyl alcohol.....	17.3	11.81	(25)
		59.5	11.21	(25)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Isobutyric acid.....	15.3	11.35	(25)
		31.8	11.15	(25)
C <sub>4</sub> H <sub>10</sub> O	Isobutyl alcohol.....	16.1	12.66	(25)
		55.2	12.03	(25)
C <sub>5</sub> H <sub>10</sub> O	Isovaleric acid.....	15.0	12.08	(25)
		33.9	11.83	(25)
C <sub>6</sub> H <sub>10</sub> O <sub>5</sub>	Dimethyl malate.....	15.3	11.8	(11)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Methyl valerate.....	17.0	11.8	(11)
C <sub>8</sub> H <sub>14</sub> O <sub>5</sub>	Diethyl malate.....	15.3	12.4	(11)
C <sub>8</sub> H <sub>14</sub> O <sub>6</sub>	Diethyl tartrate.....	15.2	12.3	(11)
C <sub>10</sub> H <sub>14</sub> O	Carvone.....	14.9	18.4	(11)
C <sub>10</sub> H <sub>16</sub>	Limonene.....	15.6	16.5	(11)
C <sub>10</sub> H <sub>16</sub>	Turpentine.....	15.8	15.7	(11)
C <sub>10</sub> H <sub>16</sub> O	Pulegone.....	14.9	16.4	(11)
C <sub>10</sub> H <sub>18</sub> O	Citronellal.....	16.4	15.1	(11)
C <sub>10</sub> H <sub>18</sub> O	Menthone.....	16.7	13.7	(11)
C <sub>10</sub> H <sub>18</sub> O <sub>6</sub>	Dipropyl tartrate.....	15.4	12.6	(11)

\*  $[\alpha]_D = 10.751$ ,  $15^{\circ}\text{C}$  (18);  $[\alpha]_{H_g} = 10.86$ ,  $t = 20^{\circ}\text{C}$  (18).†  $V_t = V_{20}\{1 - 164(t - 20) \times 10^{-4} - 1.43(t - 20)^2 \times 10^{-5}\}$  if  $0 \leq t \leq 40$ .‡ Assumes  $V_D$  for H<sub>2</sub>O at  $25^{\circ} = 0.01307'$  per cm-gauss.

TABLE 6.—VERDET CONSTANT FOR SOLUTIONS OF INORGANIC SUBSTANCES

For specific magnetic rotatory power, see Table 10; for infra-red, see Table 8

Unit of  $V = 0.001'$  per cm-gauss;  $d = 1 \text{ g cm}^{-3}$   
Temperatures ( $t$ ) in  $^{\circ}\text{C}$ ;  $\lambda_D = 5893 \text{ \AA}$ 

Solvent	Solute	$d$	$t$	$V_D$	Lit.
H <sub>2</sub> O.....	HCl	1.0762	15	16.8	(18)
	HCl	1.0758	20	16.71	(25)
	HBr	1.2039	15	19.4	(18)
	HI	1.2966	15	25.8	(18)
	HNO <sub>3</sub>	1.336	15	10.5	(18)
	H <sub>2</sub> SO <sub>4</sub> + 3H <sub>2</sub> O			12.2	(2)
	H <sub>2</sub> SO <sub>4</sub> + 3H <sub>2</sub> O	1.5507	15	12.18	(25)
	NH <sub>4</sub> OH	0.8918		15.3	(18)
	AgNO <sub>3</sub>			18.03	(2, 4)
	Bi(NO <sub>3</sub> ) <sub>3</sub>			19.22	(2, 4)
	CaCl <sub>2</sub>	1.1504	20	16.5	(12)
	Fe <sub>2</sub> Cl <sub>6</sub> *	1.6933	16	-204.1	(2, 4)
	FeCl <sub>2</sub>	1.4331	16	256	(2, 4)
	HgCl <sub>2</sub>	1.0381	16	13.7	(24)
	Hg(CN) <sub>2</sub>	1.0638	16	7.1	(24)
	KCl	1.600		16.5	(2, 4)
	KBr	1.1424	20	16.3	(12)



TABLE 6.—(Continued)

Solvent	Solute	$d$	$t$	$V_D$	Lit.
H <sub>2</sub> O.—(Cont'd)...	KI	1.6743	15	34.1	(2, 4)
	KNO <sub>3</sub>	1.0634	20	13	(12)
	KHCO <sub>3</sub>	1.1906	20	14.0	(12)
	K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	1.0786	15	12.6	(33)
	MgSO <sub>4</sub>	1.1147	16	3.6	(24)
	MnSO <sub>4</sub>	1.1212	16	4.0	(24)
	NaCl	1.2051	16	18.2	(2, 4)
	Na <sub>2</sub> SO <sub>4</sub>	1.0661	20	13.5	(12)
	Na <sub>2</sub> CO <sub>3</sub>	1.1006	20	14.0	(12)
	NiCl <sub>2</sub>	1.4685		27.3	(2, 4)
	SbCl <sub>3</sub>			29.9	(2, 4)
	SnCl <sub>2</sub>	1.3280	15	26.6	(33)
	ZnCl <sub>2</sub>	1.2851	16	19.6	(33)
	KI + HgI <sub>2</sub>	concentrated		128 ca.	(9)
HCl.....	BiCl <sub>3</sub>	2.0822	16	39.6	(2)
	SbCl <sub>3</sub>	2.4755	16	60.3	(2)
CH <sub>3</sub> OH.....	Fe <sub>2</sub> Cl <sub>6</sub>	†	19	1.592	(20)
C <sub>2</sub> H <sub>5</sub> OH.....	CaBr <sub>2</sub>	0.9966	20	15.4	(12)
	CdCl <sub>2</sub>	0.8303	20	11.8	(12)
	CdBr <sub>2</sub>	1.0446	20	15.9	(12)
	CdI <sub>2</sub>	1.0988	20	19.9	(12)
	HgCl <sub>2</sub>	0.9988	16	10.9	(24)
	HgCl <sub>2</sub>	0.8857	16	12.1	(24)
	HgI <sub>2</sub>	0.8072	16	24.4	(24)
	Hg(CN) <sub>2</sub>	0.8527	16	6.4	(24)
	Hg(CN) <sub>2</sub>	0.8348	16	5.3	(24)
	SrCl <sub>2</sub>	0.8313	20	11.8	(12)
	SrBr <sub>2</sub>	0.9636	20	14.0	(12)
C <sub>3</sub> H <sub>8</sub> O†.....	HgCl <sub>2</sub>	1.0388	21	10.8	(24)
C <sub>5</sub> H <sub>11</sub> OH§.....	HgCl <sub>2</sub>	0.8955	16	12.6	(24)
C <sub>5</sub> H <sub>5</sub> N  .....	HgCl <sub>2</sub>	1.1523	16	12.6	(24)
	HgI <sub>2</sub>	1.1054	16	23.1	(24)
	Hg(CN) <sub>2</sub>	1.2816	16	6.1	(24)

\* See also Table 11.

† 0.54Fe<sub>2</sub>Cl<sub>6</sub> + 0.46CH<sub>3</sub>OH, by weight.

‡ Acetone.

§ Amyl alcohol.

|| Pyridine.

TABLE 7.—VERDET CONSTANT FOR SOLUTIONS OF ORGANIC SUBSTANCES (25)

For specific magnetic rotatory power, see Table 10  
 Assumes for water at 4°C,  $V_{H_2O} = 0.01551'$  per cm-gauss;  $\lambda_{H_2O} = 5461 \text{ Å}$   
 Temperature ( $t$ ) in °C. Unit of  $V = 0.001'$  per cm-gauss;  
 $\lambda = 1 \text{ Å}$

100 $\tau_2$	$t$	$V$		
		$\lambda 5893$	$\lambda 5461$	$\lambda 4360$
Water (H <sub>2</sub> O)—Acetone (C <sub>3</sub> H <sub>8</sub> O)				
0.000	15.4	13.09	15.49	25.08
23.799	16	12.96	15.34	24.98
49.535	15.3	12.60	14.90	24.39
73.552	16	12.02	14.24	23.36
100.000	15.1	11.09	13.10	21.54
Water (H <sub>2</sub> O)— <i>n</i> -Propyl alcohol (C <sub>3</sub> H <sub>8</sub> O)				
0.000	15.4	13.09	15.48	25.08
20.733	15.5	13.08	15.52	25.18
39.165	14.9	12.77	15.28	24.84
100.000	17.3	11.81	14.08	22.98

TABLE 7.—(Continued)

100 $\tau_2$	$t$	$V$		
		$\lambda 5893$	$\lambda 5461$	$\lambda 4360$
CCl <sub>4</sub> —Acetic acid (C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> )				
0.000	15	16.03	18.94	31.23
35.564	15.1	13.22	15.53	25.41
58.272	14.9	12.00	13.93	23.01
78.681	15	11.11	13.06	21.34
100.000	15.2	10.35	12.16	19.91
CS <sub>2</sub> —Acetic acid (C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> )				
0.000	15.6	42.35	50.70	90.63
12.076	15.2	33.12	42.80	75.38
50.354	15.5	22.38	26.55	45.45
61.284	16.8	19.39	22.99	39.01
77.605	16	15.34	18.14	30.47
100.000	15.2	10.35	12.16	19.91
CS <sub>2</sub> —Isobutyric acid (C <sub>4</sub> H <sub>8</sub> O <sub>2</sub> )				
0.000	15.6	42.35	50.70	90.63
20.336	14.5	32.60	38.93	67.83
45.276	14.6	24.15	28.35	48.99
49.112	14.9	23.12	27.29	46.70
100.000	15	11.35	13.23	21.90
CS <sub>2</sub> —Isobutyl alcohol (C <sub>4</sub> H <sub>10</sub> O)				
0.000	15.6	42.35	50.70	90.63
15.803	16	33.99	40.50	70.78
50.080	15.7	22.73	26.88	45.95
75.360	16.5	16.94	19.96	33.56
100.000	16.1	12.66	14.86	24.35
CS <sub>2</sub> —Isovaleric acid (C <sub>5</sub> H <sub>10</sub> O <sub>2</sub> )				
0.000	15.6	42.35	50.70	90.63
32.725	15.8	28.30	33.66	58.36
46.203	16.4	24.14	28.68	49.49
50.099	15.4	23.19	27.46	47.15
63.543	17.1	19.69	23.36	39.68
100.000	15.0	12.08	14.20	23.16

TABLE 8.—VERDET CONSTANT IN INFRA-RED (13)

Temperature = 23°C; concentration expressed in % by weight;  
 unit of  $\lambda = 1\mu = 0.001 \text{ mm} = 10^4 \text{ Å}$ ;  $d = 1 \text{ g cm}^{-2}$ ;  $V = 0.001'$   
 per cm-gauss

Pure Substances		$\lambda = 0.6$	0.8	1.0	1.5	2.0
Compound						
CCl <sub>4</sub>	Carbon tetrachloride.	16.1	8.9	5.7	2.5	1.3
SnCl <sub>4</sub>	Tin tetrachloride.....	40.8	21.7	13.5	6.0	3.1
TiCl <sub>4</sub>	Titanium tetrachloride.....	-13.1	-5.0	-2.6	-1.0	-0.5
CS <sub>2</sub>	Carbon disulfide.....	39.4	21.4	13.5	5.8	3.1
H <sub>2</sub> O	Water.....	12.6	7.0	4.4	(2.9;	
					$\lambda = 1.25$ )	
CHCl <sub>3</sub>	Chloroform.....	15.5	8.6	5.6	2.4	1.3
C <sub>7</sub> H <sub>16</sub>	<i>n</i> -Heptane.....	11.9	6.6	4.3	1.8	0.9
C <sub>6</sub> H <sub>6</sub>	Benzene.....	28.1	15.3	9.5	3.9	2.2
C <sub>7</sub> H <sub>8</sub>	Toluene.....	25.8	13.7	8.7	3.5	2.0
C <sub>8</sub> H <sub>10</sub>	Xylene.....	23.2	12.8	8.0	3.5	1.9
CH <sub>3</sub> I	Methyl iodide.....	31.8	17.8	11.2	4.8	2.7
C <sub>2</sub> H <sub>5</sub> I	Ethyl iodide.....	27.9	15.1	9.7	4.1	2.4
CH <sub>2</sub> I <sub>2</sub>	Methylene iodide.....	47.6	26.8	16.9	7.3	4.0
C <sub>6</sub> H <sub>5</sub> NO <sub>2</sub>	Nitrobenzene.....	20.9	11.4	7.3	3.1	1.8
C <sub>10</sub> H <sub>7</sub> Br	$\alpha$ -Bromonaphthalene.	46.0	24.5	15.2	6.3	3.5
CH <sub>3</sub> O	Methyl alcohol.....	9.3	5.1	3.2	1.9	1.3
C <sub>2</sub> H <sub>5</sub> O	Ethyl alcohol.....	11.1	6.0	3.8	1.9	1.0
C <sub>4</sub> H <sub>10</sub> O	<i>n</i> -Butyl alcohol.....	12.0	6.7	4.3	1.8	1.4
C <sub>3</sub> H <sub>8</sub> O	Acetone.....	10.3	6.1	4.0	1.7	0.9
C <sub>4</sub> H <sub>10</sub> O	Ethyl ether.....	10.2	5.8	3.6	1.6	0.8



TABLE 8.—(Continued)

## Aqueous Solutions

Solute	$\lambda = 0.6$	0.8	1.0	1.25	$d$	%
Ce(NO <sub>3</sub> ) <sub>3</sub>	6.2	3.9	2.4	1.6	1.202	
CoCl <sub>2</sub>		9.6	6.6		1.296	
Co(NO <sub>3</sub> ) <sub>2</sub>	9.9	6.0	4.3	2.9	1.308	29.2
CoSO <sub>4</sub>		6.5	4.6		1.322	
Co(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub>	12.6	7.1	4.9	3.5	1.106	
Cr(NO <sub>3</sub> ) <sub>3</sub>		6.6	4.1	2.5	1.087	
Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		6.7	4.5	2.8	1.140	
Fe <sub>2</sub> Cl <sub>6</sub>	10.7	6.1	4.0	2.6	1.049	6.3
Fe <sub>2</sub> Cl <sub>3</sub>		39.9	21.5	11.0	1.523	47.8
Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		2.9	2.0	1.6	1.446	
FeSO <sub>4</sub>	8.7	5.0				
Fe <sub>2</sub> (NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>4</sub>	7.8	4.4	2.1	2.6	1.250	24.5
K <sub>3</sub> Fe(CN) <sub>6</sub>	23.3	5.6	1.7	0.1	1.187	31.4
K <sub>4</sub> Fe(CN) <sub>6</sub>	14.7	7.8	5.1	3.2		
K <sub>2</sub> CrO <sub>4</sub>	9.2	6.0	4.1	2.6	1.372	38.2
K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	10.8	6.4	4.2	2.5	1.085	12.1
MnCl <sub>2</sub>	14.1	7.8	5.4	3.4	1.326	31.3
MnSO <sub>4</sub>	17.8	10.1	6.6	4.3	1.369	31.0
Ni(NH <sub>4</sub> ) <sub>2</sub> (SO <sub>4</sub> ) <sub>2</sub>	13.9	7.5	4.8	3.0	1.054	
KI + HgI <sub>2</sub>	84.1	42.2	24.9	15.2	2.445	

TABLE 9.—MOLECULAR MAGNETIC ROTATORY POWER RELATIVE TO WATER ([ $\Omega$ ]).—PURE SUBSTANCES

[ $\Omega$ ] =  $M[\omega]/M'[\omega]' = MVd'/M'V'd$ , where  $M'$ ,  $[\omega]'$ ,  $V'$ ,  $d'$  refer to water at the same temperature and for the same wave-length  
 Temperature ( $t$ ) in °C;  $\lambda_D = 5893 \text{ \AA}$ ;  $\lambda_{Hg} = 5461 \text{ \AA}$ ; \* denotes [ $\Omega$ ]<sub>Hg</sub>

Formula	Name	$t$	[ $\Omega$ ] <sub>D</sub>	Lit.
CS <sub>2</sub>	Carbon disulfide.....	15	10.751	(18)
		20	10.86*	(18)
CCl <sub>4</sub>	Carbon tetrachloride.....	23.5	6.613	(18)
		25	6.599	(21)
CHBr <sub>3</sub>	Bromoform.....	20	11.614	(18)
CHCl <sub>3</sub>	Chloroform.....	15	5.575	(18)
		25	5.568	(21)
CH <sub>2</sub> Br <sub>2</sub>	Methylene bromide.....	18	8.145	(18)
CH <sub>2</sub> Cl <sub>2</sub>	Methylene chloride.....	14	4.347	(18)
CH <sub>2</sub> I <sub>2</sub>	Methylene iodide.....	17	18.83	(18)
CH <sub>3</sub> O <sub>2</sub>	Formic acid.....	20	1.653	(18)
		20	1.67*	(18)
CH <sub>3</sub> Br	Methyl bromide.....	1.5	4.644	(18)
CH <sub>3</sub> I	Methyl iodide.....	19.6	9.005	(18)
CH <sub>3</sub> O	Methyl alcohol.....	20	1.63	(18)
		20	1.60*	(18)
C <sub>2</sub> HClO <sub>2</sub>	Trichloroacetic acid.....	15	6.473	(18)
C <sub>2</sub> H <sub>2</sub> Cl <sub>2</sub> O <sub>2</sub>	Dichloroacetic acid.....	15	5.300	(18)
C <sub>2</sub> H <sub>3</sub> Br	Bromoethylene.....	11	6.203	(18)
C <sub>2</sub> H <sub>3</sub> BrCl <sub>2</sub>	1-Bromo-2, 2-dichloroethane.....	21.6	10.995	(18)
C <sub>2</sub> H <sub>3</sub> Br <sub>2</sub>	1, 1, 2-Tribromoethane.....	12	12.891	(18)
C <sub>2</sub> H <sub>3</sub> ClO	Acetyl chloride.....		3.800	(18)
C <sub>2</sub> H <sub>3</sub> ClO <sub>2</sub>	Chloroacetic acid.....	15	3.882	(18)
C <sub>2</sub> H <sub>3</sub> Cl <sub>3</sub>	1, 1, 1-Trichloroethane.....	20.8	6.762	(18)
C <sub>2</sub> H <sub>3</sub> Cl <sub>2</sub>	1, 1, 2-Trichloroethane.....	20	6.804	(18)
C <sub>2</sub> H <sub>3</sub> Br <sub>2</sub>	1, 2-Dibromoethane.....	18	9.708	(18)
C <sub>2</sub> H <sub>3</sub> Cl <sub>2</sub>	1, 1-Dichloroethane.....	15	5.34	(18)
		21	5.36	(27)
C <sub>2</sub> H <sub>3</sub> Cl <sub>2</sub>	1, 2-Dichloroethane.....	15	5.485	(18)
		21	5.518	(27)
		25	5.537	(21)
C <sub>2</sub> H <sub>4</sub> O	Acetaldehyde.....	15	2.932	(18)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Acetic acid.....	20	2.531	(18)
		20	2.49*	(18)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Methyl formate.....	16.5	2.495	(18)
		20	2.49*	(18)
C <sub>2</sub> H <sub>5</sub> Br	Ethyl bromide.....	20	5.83	(18)
C <sub>2</sub> H <sub>5</sub> Cl	Ethyl chloride.....	5	4.039	(18)
C <sub>2</sub> H <sub>5</sub> I	Ethyl iodide.....	16	10.104	(18)
C <sub>2</sub> H <sub>5</sub> O	Ethyl alcohol.....	20	2.76	(18)
		25	2.768	(21)
		20	2.76*	(18)
C <sub>2</sub> H <sub>5</sub> O <sub>2</sub>	Glycol.....	15	2.94	(18)
		20	2.88*	(18)

TABLE 9.—(Continued)

Formula	Name	$t$	[ $\Omega$ ] <sub>D</sub>	Lit.
C <sub>3</sub> H <sub>4</sub> O <sub>4</sub>	Malonic acid.....	23.2	3.474	(18)
C <sub>3</sub> H <sub>5</sub> Br	1-Bromopropylene.....	22	7.289	(18)
C <sub>3</sub> H <sub>5</sub> Br	3-Bromopropylene.....	19	8.227	(18)
C <sub>3</sub> H <sub>5</sub> Br <sub>2</sub>	1, 2, 3-Tribromopropane.....	22.8	14.050	(18)
C <sub>3</sub> H <sub>5</sub> Cl	3-Chloropropylene.....	18	6.04	(18)
C <sub>3</sub> H <sub>5</sub> Cl <sub>3</sub>	1, 2, 3-Trichloropropane.....	16	7.904	(18)
C <sub>3</sub> H <sub>5</sub> I	3-Iodopropylene.....	20	12.785	(18)
C <sub>3</sub> H <sub>5</sub> Br <sub>2</sub>	1, 2-Dibromopropane.....	15	10.827	(18)
C <sub>3</sub> H <sub>5</sub> Br <sub>2</sub>	2, 2-Dibromopropane.....	20	10.145	(18)
C <sub>3</sub> H <sub>5</sub> Br <sub>2</sub>	1, 3-Dibromopropane.....	20	10.337	(18)
C <sub>3</sub> H <sub>5</sub> Cl <sub>2</sub>	1, 2-Dichloropropane.....	15	6.328	(18)
C <sub>3</sub> H <sub>6</sub> O	Acetone.....	15.2	3.514	(18)
		25	3.471	(21)
		20	3.48*	(18)
C <sub>3</sub> H <sub>7</sub> O	Allyl alcohol.....	20	4.692	(18)
C <sub>3</sub> H <sub>7</sub> O	Propionaldehyde.....	14.4	3.335	(18)
C <sub>3</sub> H <sub>7</sub> O <sub>2</sub>	Propionic acid.....	20	3.46	(18)
		20	3.45*	(18)
C <sub>3</sub> H <sub>7</sub> O <sub>2</sub>	Ethyl formate.....	20	3.56	(18)
		20	3.55*	(18)
C <sub>3</sub> H <sub>7</sub> O <sub>2</sub>	Methyl acetate.....	22	3.36	(18)
		20	3.41*	(18)
C <sub>3</sub> H <sub>7</sub> Br	<i>n</i> -Propyl bromide.....	20	6.878	(18)
C <sub>3</sub> H <sub>7</sub> Br	Isopropyl bromide.....	18.6	6.995	(18)
C <sub>3</sub> H <sub>7</sub> Cl	Isopropyl chloride.....	19	5.160	(18)
C <sub>3</sub> H <sub>7</sub> I	<i>n</i> -Propyl iodide.....	20	11.056	(18)
C <sub>3</sub> H <sub>7</sub> I	Isopropyl iodide.....	23	11.162	(18)
C <sub>3</sub> H <sub>7</sub> O	Propyl alcohol.....	21	3.77	(18)
		20	3.74*	(18)
C <sub>3</sub> H <sub>7</sub> O	Isopropyl alcohol.....	18	4.013	(18)
		19.3	3.966	(27)
C <sub>3</sub> H <sub>7</sub> O <sub>2</sub>	Glycerol.....	16.5	4.118	(18)
		20	4.07*	(18)
C <sub>4</sub> H <sub>5</sub> Cl <sub>2</sub> O <sub>2</sub>	Fumaryl chloride.....	15.6	8.747	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Maleic anhydride.....	9.94	4.548	(18)
C <sub>4</sub> H <sub>5</sub> Cl <sub>2</sub> O <sub>2</sub>	Succinyl chloride.....	10.6	7.242	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>4</sub>	Maleic acid.....	24.8	5.633	(18)
C <sub>4</sub> H <sub>5</sub> S	Thiophene.....	15	9.578	(18)
C <sub>4</sub> H <sub>5</sub> Br <sub>2</sub>	1, 2-Dibromoisobutylene.....	15	11.88	(18)
C <sub>4</sub> H <sub>5</sub> O	Isobutyric aldehyde.....	22	4.314	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	<i>n</i> -Butyric acid.....	20	4.47	(18)
		20	4.44*	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Isobutyric acid.....	20	4.47	(18)
		20	4.44*	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Propyl formate.....	21.5	4.50	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Isopropyl formate.....	20	4.74*	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Ethyl acetate.....	18	4.46	(18)
		20	4.48*	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Methyl propionate.....	20	4.36*	(18)
C <sub>4</sub> H <sub>5</sub> Br	Isobutyl bromide.....	18.5	8.02	(18)
C <sub>4</sub> H <sub>5</sub> Br	<i>tert</i> -Butyl bromide.....	20	8.248	(18)
C <sub>4</sub> H <sub>5</sub> Cl	Isobutyl chloride.....	20	6.144	(18)
C <sub>4</sub> H <sub>5</sub> Cl	<i>tert</i> -Butyl chloride.....	17.6	6.248	(18)
C <sub>4</sub> H <sub>5</sub> I	Isobutyl iodide.....	21	12.183	(18)
C <sub>4</sub> H <sub>5</sub> O	Ethyl ether.....	20	4.77	(18)
		20	4.80*	(18)
C <sub>4</sub> H <sub>5</sub> O	<i>n</i> -Butyl alcohol.....	20	4.72*	(18)
C <sub>4</sub> H <sub>5</sub> O	Isobutyl alcohol.....	20	4.95	(18)
C <sub>4</sub> H <sub>5</sub> O	Trimethyl carbinol.....	22	5.107	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Dimethyl acetal.....	15.5	4.64	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>4</sub>	Erythritol.....	15	5.23	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Citraconic anhydride.....	15.6	5.540	(18)
C <sub>4</sub> H <sub>5</sub> N	Pyridine.....	15	8.748	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Pyrotartaric anhydride.....	11.6	4.764	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>4</sub>	Citraconic acid.....	15.6	6.567	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>4</sub>	Dimethyl malonate.....	18	5.273	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>4</sub>	Glutaric acid.....	13.3	5.482	(18)
C <sub>4</sub> H <sub>5</sub>	<i>n</i> -Propylethylene.....	18	6.113	(18)
		23.6	6.180	(27)
C <sub>4</sub> H <sub>5</sub> Br <sub>2</sub>	2, 3-Dibromoisopentane.....	14.4	12.933	(18)
C <sub>4</sub> H <sub>5</sub> O	Isovaleraldehyde.....	14.5	5.478	(18)
C <sub>4</sub> H <sub>5</sub> O	Diethyl ketone.....	21	5.434	(27)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Valeric acid.....	14	5.50	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Isovaleric acid.....	16	5.65	(18)
		20	5.57*	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Propyl acetate.....	15	5.49	(18)
		20	5.45*	(18)
C <sub>4</sub> H <sub>5</sub> O <sub>2</sub>	Ethyl propionate.....	15	5.456	(18)



TABLE 9.—(Continued)

Formula	Name	<i>t</i>	[ <i>Q</i> ] <sub>D</sub>	Lit.
C <sub>4</sub> H <sub>10</sub> O <sub>2</sub>	Methyl butyrate.....	16.4	5.38	(18)
		20	5.37*	(15)
C <sub>5</sub> H <sub>11</sub> Br	Isoamyl bromide.....	18	9.073	(18)
C <sub>5</sub> H <sub>11</sub> Cl	Isoamyl chloride.....	20	7.169	(18)
C <sub>5</sub> H <sub>11</sub> Cl	<i>tert.</i> -Amyl chloride.....	22	7.206	(18)
C <sub>5</sub> H <sub>11</sub> I	Isoamyl iodide.....	18	13.246	(18)
C <sub>5</sub> H <sub>12</sub>	Pentane.....	20	5.647	(18)
		21.1	5.811	(27)
C <sub>5</sub> H <sub>12</sub>	Isopentane.....	21.5	5.76	(18)
C <sub>5</sub> H <sub>12</sub> O	Ethyl dimethyl carbinol.....	20	5.99	(18)
C <sub>5</sub> H <sub>12</sub> O	<i>act.</i> -Amyl alcohol.....	20	5.95	(18)
C <sub>5</sub> H <sub>12</sub> O	Isobutyl carbinol.....	20	5.96	(18)
C <sub>5</sub> H <sub>8</sub> N <sub>2</sub> O <sub>4</sub>	<i>m</i> -Dinitrobenzene.....	15	9.647	(18)
C <sub>6</sub> H <sub>5</sub> Br	Bromobenzene.....	15	14.506	(18)
C <sub>6</sub> H <sub>5</sub> Cl	Chlorobenzene.....	15	12.510	(18)
C <sub>6</sub> H <sub>5</sub> F	Fluorobenzene.....	15	9.970	(18)
C <sub>6</sub> H <sub>5</sub> I	Iodobenzene.....	15	19.108	(18)
C <sub>6</sub> H <sub>5</sub> NO <sub>2</sub>	Nitrobenzene.....	15	9.361	(18)
C <sub>6</sub> H <sub>5</sub> N <sub>3</sub>	Triazobenzene.....	15	14.769	(18)
C <sub>6</sub> H <sub>6</sub>	Benzene.....	15	11.284	(18)
		25	11.23	(31)
		27	11.23	(27)
C <sub>6</sub> H <sub>7</sub> CIN	<i>m</i> -Chloroaniline.....	15	16.969	(18)
C <sub>6</sub> H <sub>7</sub> CIN	<i>p</i> -Chloroaniline.....	15	17.066	(18)
C <sub>6</sub> H <sub>6</sub> O	Phenol.....	15	12.14	(18)
C <sub>6</sub> H <sub>6</sub> O <sub>2</sub>	Resorcinol.....	15	12.285	(18)
C <sub>6</sub> H <sub>6</sub> O <sub>2</sub>	Pyrocatechol.....	15	13.022	(18)
C <sub>6</sub> H <sub>6</sub> O <sub>3</sub>	Pyrogallol.....	15	13.029	(18)
C <sub>6</sub> H <sub>7</sub> N	Aniline.....	15	16.076	(18)
C <sub>6</sub> H <sub>7</sub> CIN	Aniline hydrochloride (anhydrous).....	15	16.394	(18)
C <sub>6</sub> H <sub>7</sub> CIN	Aniline hydrochloride (in solution).....	15	15.547	(18)
C <sub>6</sub> H <sub>8</sub> N <sub>2</sub>	<i>o</i> -Phenylenediamine.....	15	19.391	(18)
C <sub>6</sub> H <sub>8</sub> N <sub>2</sub>	<i>m</i> -Phenylenediamine.....	15	18.843	(18)
C <sub>6</sub> H <sub>8</sub> N <sub>2</sub>	Phenylhydrazine.....	15	18.061	(18)
C <sub>6</sub> H <sub>10</sub> Cl <sub>2</sub> N <sub>2</sub>	<i>o</i> -Phenylenediamine hydrochloride (in solution).....	15	21.329	(18)
C <sub>6</sub> H <sub>10</sub> Cl <sub>2</sub> N <sub>2</sub>	<i>m</i> -Phenylenediamine hydrochloride (in solution).....	15	20.345	(18)
C <sub>6</sub> H <sub>10</sub> Cl <sub>2</sub> N <sub>2</sub>	<i>p</i> -Phenylenediamine hydrochloride (in solution).....	15	20.213	(18)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	Ethyl <i>α</i> -crotonate.....	22.5	7.567	(18)
C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>	Ethyl acetacetate.....	19	6.48	(18)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Glycol diacetate.....	15	6.43	(18)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Diethyl oxalate.....	15	6.636	(18)
C <sub>6</sub> H <sub>10</sub> O <sub>4</sub>	Dimethyl succinate.....	18.5	6.242	(18)
C <sub>6</sub> H <sub>12</sub>	Hexylene.....	24	7.453	(27)
C <sub>6</sub> H <sub>12</sub> O	Pinacolin.....	20	6.32*	(18)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Isobutyl acetate.....	10	6.63	(18)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Propyl propionate.....	20	6.42	(18)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Isopropyl propionate.....	18	6.60	(18)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Ethyl butyrate.....	19	6.50	(18)
C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	Ethyl isobutyrate.....	18.8	6.48	(18)
C <sub>6</sub> H <sub>12</sub> O <sub>3</sub>	Paraldehyde.....	18	6.653	(18)
C <sub>6</sub> H <sub>12</sub> O <sub>4</sub>	Fructose.....	15	6.789	(19)
C <sub>6</sub> H <sub>12</sub> O <sub>4</sub>	Galactose.....	15	6.887	(19)
C <sub>6</sub> H <sub>12</sub> O <sub>4</sub>	Glucose.....	15	6.723	(19)
C <sub>6</sub> H <sub>13</sub> I	<i>sec.</i> -Hexyl iodide.....	22	14.243	(18)
C <sub>6</sub> H <sub>14</sub>	Diisopropyl.....	15	6.784	(18)
C <sub>6</sub> H <sub>14</sub>	Hexane.....	11	6.67	(18)
		22.5	6.66	(27)
		20	6.62*	(15)
C <sub>6</sub> H <sub>14</sub>	Isobutane.....	20	6.785	(18)
C <sub>6</sub> H <sub>14</sub> O	2, 2-Dimethyl-3-butanol.....	20	7.06*	(18)
C <sub>6</sub> H <sub>14</sub> O <sub>2</sub>	Diethyl acetal.....	15	6.96	(18)
C <sub>6</sub> H <sub>14</sub> O <sub>2</sub>	Pinacol.....	21	7.23	(18)
C <sub>6</sub> H <sub>14</sub> O <sub>3</sub>	Mannitol.....	15	7.351	(19)
C <sub>7</sub> H <sub>5</sub> ClO	Benzoyl chloride.....	15	12.385	(18)
C <sub>7</sub> H <sub>5</sub> N	Benzonitrile.....	15	11.857	(18)
C <sub>7</sub> H <sub>5</sub> NS	Phenyl isothiocyanate.....	15	21.526	(18)
C <sub>7</sub> H <sub>6</sub> O	Benzaldehyde.....	15	11.864	(18)
C <sub>7</sub> H <sub>6</sub> O <sub>2</sub>	Salicyl aldehyde.....	15	13.286	(18)
C <sub>7</sub> H <sub>7</sub> Br	<i>o</i> -Bromotoluene.....	15	15.674	(18)
C <sub>7</sub> H <sub>7</sub> Br	<i>p</i> -Bromotoluene.....	15	15.167	(18)
C <sub>7</sub> H <sub>7</sub> Cl	<i>o</i> -Chlorotoluene.....	15	13.719	(18)
C <sub>7</sub> H <sub>7</sub> Cl	<i>p</i> -Chlorotoluene.....	15	13.246	(18)
C <sub>7</sub> H <sub>7</sub> NO	Benzamide.....	15	13.520	(18)
C <sub>7</sub> H <sub>7</sub> NO	Formanilide.....	15	15.211	(18)
C <sub>7</sub> H <sub>7</sub> NO <sub>2</sub>	<i>o</i> -Nitrotoluene.....	15	10.806	(18)
C <sub>7</sub> H <sub>7</sub> NO <sub>2</sub>	<i>p</i> -Nitrotoluene.....	15	10.214	(18)

TABLE 9.—(Continued)

Formula	Name	<i>t</i>	[ <i>Q</i> ] <sub>D</sub>	Lit.
C <sub>7</sub> H <sub>8</sub>	Toluene.....	15	12.157	(18)
		28.4	12.031	(27)
C <sub>7</sub> H <sub>8</sub> O	Benzyl alcohol.....	15	12.400	(18)
C <sub>7</sub> H <sub>8</sub> O	<i>o</i> -Cresol.....	15	13.382	(18)
C <sub>7</sub> H <sub>8</sub> O	<i>m</i> -Cresol.....	15	12.776	(18)
C <sub>7</sub> H <sub>8</sub> O	<i>p</i> -Cresol.....	15	12.869	(18)
C <sub>7</sub> H <sub>8</sub> O	Phenyl methyl ether.....	15	13.958	(18)
C <sub>7</sub> H <sub>8</sub> O <sub>2</sub>	Homopyrocatechol.....	15	13.306	(18)
C <sub>7</sub> H <sub>8</sub> O <sub>2</sub>	Guaiacol.....	15	14.689	(18)
C <sub>7</sub> H <sub>9</sub> N	<i>o</i> -Toluidine.....	15	17.200	(18)
C <sub>7</sub> H <sub>9</sub> N	<i>m</i> -Toluidine.....	15	16.210	(18)
C <sub>7</sub> H <sub>9</sub> N	<i>p</i> -Toluidine.....	15	16.188	(18)
C <sub>7</sub> H <sub>9</sub> N	Methylaniline.....	15	19.624	(18)
C <sub>7</sub> H <sub>9</sub> N	Benzylamine.....	15	13.646	(18)
C <sub>7</sub> H <sub>9</sub> NO	<i>o</i> -Anisidine.....	15	18.722	(18)
C <sub>7</sub> H <sub>9</sub> NO	<i>p</i> -Anisidine.....	15	18.306	(18)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Dimethyl mesaconate.....	14.4	9.061	(18)
C <sub>7</sub> H <sub>10</sub> O <sub>4</sub>	Dimethyl citraconate.....	13	8.364	(18)
C <sub>7</sub> H <sub>12</sub> O <sub>2</sub>	Dimethylacetylacetone.....	15	7.045	(18)
C <sub>7</sub> H <sub>12</sub> O <sub>4</sub>	Diethyl malonate.....	15	7.41	(18)
C <sub>7</sub> H <sub>14</sub> O	Dipropyl ketone.....	15	7.47	(18)
		20	7.32*	(15)
C <sub>7</sub> H <sub>14</sub> O	Diisopropyl ketone.....	20	7.36*	(15)
C <sub>7</sub> H <sub>14</sub> O	Heptaldehyde.....	19	7.405	(18)
C <sub>7</sub> H <sub>14</sub> O <sub>2</sub>	<i>n</i> -Heptylic acid.....	20	7.55	(18)
C <sub>7</sub> H <sub>14</sub> O <sub>2</sub>	Ethyl isovalerate.....	19.5	7.60	(18)
C <sub>7</sub> H <sub>16</sub>	<i>n</i> -Heptane.....	15	6.666	(18)
C <sub>7</sub> H <sub>16</sub> O	<i>n</i> -Heptyl alcohol.....	15	7.84	(18)
		20	7.78*	(15)
C <sub>8</sub> H <sub>4</sub> Cl <sub>2</sub> O <sub>2</sub>	Phthalyl chloride.....	15	14.183	(18)
C <sub>8</sub> H <sub>6</sub> O	Coumarone.....	15	14.807	(18)
C <sub>8</sub> H <sub>7</sub> ClO	<i>ω</i> -Chloroacetophenone.....	15	14.091	(18)
C <sub>8</sub> H <sub>7</sub> N	<i>o</i> -Tolunitrile.....	15	12.980	(18)
C <sub>8</sub> H <sub>7</sub> N	<i>p</i> -Tolunitrile.....	15	12.999	(18)
C <sub>8</sub> H <sub>7</sub> N	Benzyl cyanide.....	15	12.472	(18)
C <sub>8</sub> H <sub>8</sub>	Phenylethylene.....	15	16.041	(18)
C <sub>8</sub> H <sub>8</sub> O	Acetophenone.....	15	12.597	(18)
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub>	Phenyl acetate.....	15	12.953	(18)
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub>	Phenylacetic acid.....	15	12.743	(18)
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub>	Methyl benzoate.....	15	12.743	(18)
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub>	<i>o</i> -Methoxybenzaldehyde.....	15	14.187	(18)
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub>	Anisaldehyde.....	15	15.872	(18)
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub>	Methyl salicylate.....	15	14.266	(18)
C <sub>8</sub> H <sub>8</sub> NO	Acetanilide.....	15	16.003	(18)
C <sub>8</sub> H <sub>8</sub> NO	Phenylacetamide.....	15	15.208	(18)
C <sub>8</sub> H <sub>10</sub>	<i>o</i> -Xylene.....	15	13.345	(18)
		27	13.306	(27)
C <sub>8</sub> H <sub>10</sub>	<i>m</i> -Xylene.....	15	12.859	(18)
		28.4	12.731	(27)
C <sub>8</sub> H <sub>10</sub>	<i>p</i> -Xylene.....	15	12.810	(18)
		27	12.789	(27)
C <sub>8</sub> H <sub>10</sub>	Ethylbenzene.....	15	13.414	(18)
		28.2	13.327	(27)
C <sub>8</sub> H <sub>10</sub> O	<i>o</i> -Tolyl methyl ether.....	15	15.190	(18)
C <sub>8</sub> H <sub>10</sub> O	<i>m</i> -Tolyl methyl ether.....	15	14.646	(18)
C <sub>8</sub> H <sub>10</sub> O	<i>p</i> -Tolyl methyl ether.....	15	14.712	(18)
C <sub>8</sub> H <sub>10</sub> O	Benzyl methyl ether.....	15	13.417	(18)
C <sub>8</sub> H <sub>10</sub> O	Phenyl ethyl ether.....	15	15.129	(18)
C <sub>8</sub> H <sub>10</sub> O	Phenylmethyl carbinol.....	20	16.01*	(15)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>	Anisyl alcohol.....	15	15.407	(18)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>	Creosol.....	15	15.405	(18)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>	Dimethylresorcinol.....	15	15.108	(18)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>	Dimethylquinol.....	15	16.717	(18)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>	Methylsaligenin.....	15	14.828	(18)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>	3-Hydroxy-4-methoxytoluene.....	15	15.021	(18)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>	Veratrol.....	15	16.837	(18)
C <sub>8</sub> H <sub>10</sub> O <sub>4</sub>	Diethyl acetylenedicarboxylate.....	25	9.617	(16)
C <sub>8</sub> H <sub>11</sub> N	Ethylaniline.....	15	20.567	(18)
C <sub>8</sub> H <sub>11</sub> N	Dimethylaniline.....	15	22.888	(18)
C <sub>8</sub> H <sub>11</sub> CIN	Dimethylaniline hydrochloride (anhydrous).....	15	18.326	(18)
C <sub>8</sub> H <sub>11</sub> CIN	Dimethylaniline hydrochloride (in solution).....	15	17.604	(18)
C <sub>8</sub> H <sub>11</sub> N <sub>2</sub>	<i>p</i> -Aminodimethylaniline.....	15	26.239	(18)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	Diethyl fumarate.....	11.1	10.112	(16)
C <sub>8</sub> H <sub>12</sub> O <sub>4</sub>	Diethyl maleate.....	15	9.625	(16)
C <sub>8</sub> H <sub>12</sub> NO	Amylpropionamide.....	25	10.653	(17)
C <sub>8</sub> H <sub>14</sub>	<i>n</i> -Hexylacetylene.....	25	9.310	(17)
C <sub>8</sub> H <sub>14</sub> O <sub>4</sub>	Glycol dipropionate.....	15	8.349	(16)



TABLE 9.—(Continued)

Formula	Name	t	[ $\eta$ ]D	Lit.
C <sub>8</sub> H <sub>14</sub> O <sub>4</sub>	Diethyl succinate.....	20	8.379	(18)
C <sub>8</sub> H <sub>14</sub> O <sub>4</sub>	Diethyl isosuccinate.....	19.2	8.324	(18)
C <sub>8</sub> H <sub>16</sub>	Octylene.....	24	9.406	(27)
C <sub>8</sub> H <sub>16</sub> O	Isopropyl <i>n</i> -butyl ketone.....	20	8.43*	(15)
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	Caprylic acid.....	20	8.56	(18)
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	Ethyl caproate.....	18.8	8.502	(18)
C <sub>8</sub> H <sub>17</sub> Cl	Octyl chloride.....	20	10.138	(18)
C <sub>8</sub> H <sub>17</sub> Cl	<i>sec</i> -Octyl chloride.....	20	10.25	(18)
C <sub>8</sub> H <sub>17</sub> I	Octyl iodide.....	19.3	16.213	(18)
C <sub>8</sub> H <sub>18</sub>	Octane.....	23.1	8.722	(27)
C <sub>8</sub> H <sub>18</sub> O	Octyl alcohol.....	20	8.89	(18)
		20	8.87*	(15)
C <sub>8</sub> H <sub>18</sub> O	<i>sec</i> -Octyl alcohol.....	13.5	8.99	(18)
C <sub>8</sub> H <sub>8</sub> O <sub>2</sub>	Phenylpropionic acid.....	25	16.659†	(17)
C <sub>8</sub> H <sub>7</sub> N	Quinoline.....	15	20.875	(18)
C <sub>8</sub> H <sub>7</sub> NO	Phenylpropionamide.....	25	18.43†	(17)
C <sub>8</sub> H <sub>8</sub>	Indene (synthetic).....	15	16.202	(18)
C <sub>8</sub> H <sub>8</sub> O	Hydrindone.....	15	13.768	(18)
C <sub>8</sub> H <sub>8</sub> O	Cinnamaldehyde.....	15	17.885	(18)
C <sub>8</sub> H <sub>10</sub>	Allylbenzene.....	15	17.599	(18)
C <sub>8</sub> H <sub>10</sub>	Hydrindene (synthetic).....	15	13.928	(18)
C <sub>8</sub> H <sub>10</sub> O	Cinnamic alcohol.....	15	17.940	(18)
C <sub>8</sub> H <sub>10</sub> O	Phenyl allyl ether.....	15	17.134	(18)
C <sub>8</sub> H <sub>10</sub> O	Phenyl ethyl ketone.....	15	13.635	(18)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>	Phenyl propionate.....	15	13.673	(18)
C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>	Ethyl salicylate.....	15	15.366	(18)
C <sub>8</sub> H <sub>11</sub> N	Tetrahydroquinoline.....	15	19.619	(18)
C <sub>8</sub> H <sub>12</sub>	Propylbenzene.....	15	14.553	(18)
		25.6	14.394	(27)
C <sub>8</sub> H <sub>12</sub>	Isopropylbenzene.....	15	14.633	(18)
		27	14.440	(27)
C <sub>8</sub> H <sub>12</sub>	Mesitylene.....	15	13.366	(18)
		28.6	12.920	(27)
C <sub>8</sub> H <sub>12</sub>	Pseudocumene.....	15	13.998	(18)
		24.6	13.767	(27)
C <sub>8</sub> H <sub>12</sub> O	Phenyl propyl ether.....	15	16.187	(18)
C <sub>8</sub> H <sub>12</sub> O	Phenyl isopropyl ether.....	15	16.210	(18)
C <sub>8</sub> H <sub>12</sub> O	Benzylmethyl carbinol.....	20	13.87*	(15)
C <sub>8</sub> H <sub>12</sub> O	Phenylethyl carbinol.....	20	14.92*	(15)
C <sub>8</sub> H <sub>12</sub> O <sub>2</sub>	Dimethylhomopyrocatechol.....	15	17.484	(18)
C <sub>8</sub> H <sub>12</sub> O <sub>2</sub>	Trimethylpyrogallol.....	15	17.201	(18)
C <sub>8</sub> H <sub>12</sub> N	Dimethyl <i>p</i> -toluidine.....	15	18.617	(18)
C <sub>8</sub> H <sub>12</sub> N	Dimethyl <i>p</i> -toluidine.....	15	22.842	(18)
C <sub>8</sub> H <sub>14</sub> ClN	Dimethyl- <i>o</i> -toluidine hydrochloride (in solution).....	15	18.705	(18)
C <sub>8</sub> H <sub>14</sub> ClN	Dimethyl- <i>p</i> -toluidine hydrochloride (in solution).....	15	18.465	(18)
		25	10.598	(17)
C <sub>8</sub> H <sub>14</sub> O <sub>2</sub>	Hexylpropionic acid.....	15	10.39	(18)
C <sub>8</sub> H <sub>14</sub> O <sub>2</sub>	Ethyl allylacetate.....	15	10.497	(18)
C <sub>8</sub> H <sub>14</sub> O <sub>4</sub>	Diethyl citraconate.....	15	11.233	(18)
C <sub>8</sub> H <sub>14</sub> O <sub>4</sub>	Diethyl mesaconate.....	16.3	11.233	(18)
C <sub>8</sub> H <sub>14</sub> O <sub>4</sub>	Diethyl itaconate.....	17.0	10.467	(18)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Diethyl dimethylmalonate.....	18.5	9.24	(18)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Diethyl ethylmalonate.....	15	9.27	(18)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Diethyl methylsuccinate.....	18.5	9.332	(18)
C <sub>8</sub> H <sub>16</sub> O <sub>4</sub>	Diethyl glutarate.....	12.5	9.356	(18)
C <sub>8</sub> H <sub>16</sub> O	Isopropyl <i>n</i> -amyl ketone.....	20	9.40*	(15)
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	Nonylic acid.....	20	9.60	(18)
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	Ethyl oenanthate.....	15	9.54	(18)
C <sub>10</sub> H <sub>7</sub> NO <sub>2</sub>	$\alpha$ -Nitronaphthalene.....	15	20.840	(18)
C <sub>10</sub> H <sub>8</sub>	Naphthalene.....	15	25.125	(18)
C <sub>10</sub> H <sub>8</sub> O	Acetylphenylacetylene.....	25	17.146	(17)
C <sub>10</sub> H <sub>8</sub> O <sub>2</sub>	Methyl phenylpropionate.....	25	17.752	(17)
C <sub>10</sub> H <sub>9</sub> N	$\alpha$ -Naphthylamine.....	15	37.478	(18)
C <sub>10</sub> H <sub>9</sub> N	$\beta$ -Naphthylamine.....	15	35.700	(18)
C <sub>10</sub> H <sub>10</sub> O	Benzalacetone.....	15	19.235	(18)
C <sub>10</sub> H <sub>10</sub> O <sub>2</sub>	Allyl benzoate.....	15	15.722	(18)
C <sub>10</sub> H <sub>12</sub>	Isobutenylbenzene.....	15	18.362	(18)
C <sub>10</sub> H <sub>12</sub> O	Cuminaldehyde.....	15	15.245	(18)
C <sub>10</sub> H <sub>12</sub> O	<i>p</i> -Tolyl allyl ether.....	15	17.571	(18)
C <sub>10</sub> H <sub>12</sub> O	Anethol.....	15	21.089	(18)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Ethyl <i>o</i> -toluate.....	15	15.065	(18)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Ethyl <i>p</i> -toluate.....	15	14.744	(18)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Phenyl butyrate.....	15	14.761	(18)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Ethyl phenylacetate.....	15	14.982	(18)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Propyl benzoate.....	15	14.873	(18)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Isopropyl benzoate.....	15	14.950	(18)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Eugenol.....	15	18.727	(18)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Ethyl anisate.....	15	17.285	(18)

TABLE 9.—(Continued)

Formula	Name	t	[ $\eta$ ]D	Lit.
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Ethyl <i>o</i> -methoxybenzoate.....	15	17.156	(18)
C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	Ethyl <i>m</i> -methoxybenzoate.....	15	16.679	(18)
C <sub>10</sub> H <sub>12</sub> Br <sub>2</sub> ClO	$\alpha$ , $\beta$ -Dibromochlorocamphor§.....	13.1	17.303	(18)
C <sub>10</sub> H <sub>12</sub> N	$\alpha$ -Tetrahydro- $\beta$ -naphthylamine.....	15	20.058	(18)
C <sub>10</sub> H <sub>12</sub> N	$\alpha$ -Tetrahydro- $\beta$ -naphthylamine.....	15	16.147	(18)
C <sub>10</sub> H <sub>14</sub>	Isobutylbenzene.....	15	15.615	(18)
		23.6	15.531	(27)
C <sub>10</sub> H <sub>14</sub>	Cymene.....	15	15.255	(18)
		25.7	14.892	(27)
C <sub>10</sub> H <sub>14</sub> BrNO <sub>2</sub>	$\alpha$ , $\alpha'$ -Bromonitrocamphor§  .....	12.7	12.720	(18)
C <sub>10</sub> H <sub>14</sub> Br <sub>2</sub> O	$\alpha$ , $\alpha'$ -Dibromocamphor§  .....	15.52	15.994	(18)
C <sub>10</sub> H <sub>14</sub> Br <sub>2</sub> O	$\alpha$ , $\beta$ -Dibromocamphor§  .....	14.9	15.902	(18)
C <sub>10</sub> H <sub>14</sub> ClNO <sub>2</sub>	$\alpha$ , $\alpha'$ -Chloronitrocamphor§**.....	12.85	10.822	(18)
C <sub>10</sub> H <sub>14</sub> O	Cumyl alcohol.....	15	15.879	(18)
C <sub>10</sub> H <sub>14</sub> O	Phenyl isobutyl ether.....	15	17.332	(18)
C <sub>10</sub> H <sub>14</sub> O	<i>l</i> -Phenylethylmethyl carbinol.....	20	14.93*	(18)
C <sub>10</sub> H <sub>14</sub> O	Carvacrol.....	15	16.313	(18)
C <sub>10</sub> H <sub>14</sub> O	Thymol.....	15	16.120	(18)
C <sub>10</sub> H <sub>16</sub> BrO	$\alpha$ -Bromocamphor§**.....	12.2	12.761	(18)
C <sub>10</sub> H <sub>16</sub> ClO	$\alpha$ -Chlorocamphor§††.....	12.4	10.846	(18)
C <sub>10</sub> H <sub>16</sub> N	Diethylaniline.....	15	25.163	(18)
C <sub>10</sub> H <sub>16</sub> NO <sub>2</sub>	Camphoryloxime§††.....	17.4	10.375	(18)
C <sub>10</sub> H <sub>16</sub> NO <sub>2</sub>	$\alpha$ -Nitrocamphor§§§.....	12.14	9.468	(18)
C <sub>10</sub> H <sub>16</sub>	Camphene.....	45.8	10.136	(18)
C <sub>10</sub> H <sub>16</sub>	<i>d</i> -Limonene.....	16.32	11.246	(18)
C <sub>10</sub> H <sub>16</sub>	<i>l</i> -Limonene.....	15	11.162	(18)
C <sub>10</sub> H <sub>16</sub>	Pinene.....	20	10.294	(18)
C <sub>10</sub> H <sub>16</sub> O	Camphor§   .....	15.74	9.280	(18)
C <sub>10</sub> H <sub>16</sub> O <sub>2</sub>	Ethyl amylpropionate.....	25	11.556	(17)
C <sub>10</sub> H <sub>16</sub> O <sub>2</sub>	Methyl hexylpropionate.....	25	13.730	(17)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	Diethyl allylmalonate.....	14	11.265	(18)
C <sub>10</sub> H <sub>16</sub> O <sub>4</sub>	Diethyl acetosuccinate.....	22.5	10.33	(18)
C <sub>10</sub> H <sub>17</sub> Cl	Pinene hydrochloride¶¶.....	14.8	11.058	(18)
C <sub>10</sub> H <sub>18</sub> Cl <sub>2</sub>	Dipentene dihydrochloride.....	54.8	13.111	(18)
C <sub>10</sub> H <sub>18</sub> O	Borneol§***.....	15.8	9.807	(18)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	Diethyl propylmalonate.....	20	10.36	(18)
C <sub>10</sub> H <sub>18</sub> O <sub>4</sub>	Diethyl isopropylmalonate.....	20	10.47	(18)
C <sub>10</sub> H <sub>19</sub> N	Camphylamine.....	16	11.770	(18)
C <sub>10</sub> H <sub>20</sub>	Decylene.....	23.7	11.247	(27)
C <sub>10</sub> H <sub>20</sub> O	Isobutyl amyl ketone.....	20	10.65*	(15)
C <sub>10</sub> H <sub>20</sub> O <sub>2</sub>	Octyl acetate.....	15	10.63	(18)
C <sub>10</sub> H <sub>22</sub>	Decane.....	23	8.722	(27)
		20	8.70*	(15)
C <sub>10</sub> H <sub>22</sub> O	Isoamyl ether.....	15.6	11.168	(18)
C <sub>10</sub> H <sub>22</sub> O	Isopropyl <i>n</i> -hexyl ketone.....	20	10.44*	(15)
C <sub>11</sub> H <sub>7</sub> N	$\alpha$ -Naphthonitrile.....	15	24.788	(18)
C <sub>11</sub> H <sub>7</sub> N	$\beta$ -Naphthonitrile.....	15	26.264	(18)
C <sub>11</sub> H <sub>10</sub> O	Propionylphenylacetylene.....	25	18.595	(17)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	Ethyl phenylpropionate.....	25	18.965	(17)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	Ethyl cinnamate.....	15	20.006	(18)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	Ethyl benzoyleacetate.....	15	16.411	(18)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	$\alpha$ -Methyl <i>o</i> -methoxyphenylacrylate.....	15	21.891	(18)
C <sub>11</sub> H <sub>10</sub> O <sub>2</sub>	$\beta$ -Methyl <i>o</i> -methoxyphenylacrylate.....	15	22.359	(18)
C <sub>11</sub> H <sub>14</sub> O <sub>2</sub>	Butyl benzoate.....	15	15.952	(18)
C <sub>11</sub> H <sub>14</sub> O <sub>2</sub>	Isobutyl benzoate.....	15	16.048	(18)
C <sub>11</sub> H <sub>14</sub> O <sub>2</sub>	Ethyl hydrocinnamate.....	15	16.169	(18)
C <sub>11</sub> H <sub>16</sub> O <sub>2</sub>	Ethyl hexylpropionate.....	25	12.576	(17)
C <sub>11</sub> H <sub>20</sub> O <sub>4</sub>	Diethyl diethylmalonate.....	20.5	11.20	(18)
C <sub>11</sub> H <sub>22</sub> O <sub>2</sub>	Ethyl pelargonate.....	18	11.56	(18)
C <sub>12</sub> H <sub>10</sub>	Diphenyl.....	15	25.304	(18)
C <sub>12</sub> H <sub>10</sub> S	Diphenyl sulfide.....	15	29.668	(18)
C <sub>12</sub> H <sub>12</sub> O	$\alpha$ -Naphthyl ethyl ether.....	15	32.237	(18)
C <sub>12</sub> H <sub>12</sub> O	$\beta$ -Naphthyl ethyl ether.....	15	30.698	(18)
C <sub>12</sub> H <sub>12</sub> O	Butyrylphenylacetylene.....	25	19.911	(17)
C <sub>12</sub> H <sub>12</sub> N	Dimethyl- $\alpha$ -naphthylamine.....	15	35.994	(18)
C <sub>12</sub> H <sub>12</sub> N	Dimethyl- $\beta$ -naphthylamine.....	15	47.377	(18)
C <sub>12</sub> H <sub>14</sub> O <sub>4</sub>	Diethyl phthalate.....	15	16.909	(18)
C <sub>12</sub> H <sub>14</sub> O <sub>4</sub>	Diethyl isophthalate.....	15	16.942	(18)
C <sub>12</sub> H <sub>14</sub> O <sub>4</sub>	Diethyl terephthalate.....	15	16.117	(18)
C <sub>12</sub> H <sub>16</sub> O <sub>2</sub>	Ethyl cumate.....	15	17.093	(18)
C <sub>12</sub> H <sub>17</sub> O <sub>4</sub>	Diisobutyl succinate.....	15	12.71	(18)
C <sub>12</sub> H <sub>17</sub> O <sub>4</sub>	Diethyl suberate.....	17.5	12.45	(18)
C <sub>12</sub> H <sub>22</sub> O <sub>11</sub>	Maltose.....	15	12.690	(18)
C <sub>12</sub> H <sub>22</sub> O <sub>11</sub>	Lactose.....	15	12.714	(18)
C <sub>12</sub> H <sub>22</sub> O <sub>11</sub>	Saccharose.....	15	12.586	(18)
C <sub>12</sub> H <sub>24</sub> O	Isopropyl <i>n</i> -octyl ketone.....	20	12.48*	(15)
C <sub>12</sub> H <sub>26</sub> O <sub>4</sub>	Diacetol.....	25	13.61	(17)
C <sub>12</sub> H <sub>26</sub> O	Benzophenone.....	15	23.371	(18)
C <sub>12</sub> H <sub>28</sub>	Diphenylmethane.....	15	23.845	(18)



TABLE 9.—(Continued)

Formula	Name	$t$	$[\alpha]_D$	Lit.
$C_{12}H_{12}O_2$	Ethyl $\alpha$ -naphthoate.....	15	27.161	(18)
$C_{12}H_{12}O_2$	Ethyl $\beta$ -naphthoate.....	15	27.360	(18)
$C_{12}H_{12}N$	Methyldiphenylamine.....	15	34.878	(18)
$C_{12}H_{12}N$	Benzylaniline.....	15	31.295	(18)
$C_{12}H_{14}O$	Isovalerylphenylacetylene.....	25	21.168	(17)
$C_{12}H_{14}O_2$	Phenyl oenanthate.....	15	17.923	(18)
$C_{12}H_{16}O_4$	Diethyl diallylmalonate.....	22	14.99	(18)
$C_{14}H_{10}$	Phenanthrene.....	15	36.959	(18)
$C_{14}H_{12}$	Stilbene.....	15	33.143	(18)
$C_{14}H_{14}$	Dibenzyl.....	15	24.977	(18)
$C_{14}H_{14}S$	Dibenzyl sulfide.....	15	29.216	(18)
$C_{14}H_{16}N$	Dibenzylamine.....	15	25.879	(18)
$C_{14}H_{16}O$	Caproylphenylacetylene.....	25	21.435	(17)
$C_{14}H_{18}O$	Phenyl octyl ether.....	15	21.446	(18)
$C_{14}H_{18}O_4$	Diethyl sebacate.....	15	14.51	(18)
$C_{14}H_{20}O_2$	Heptyl oenanthate.....	15	14.64	(18)
$C_{15}H_{16}O$	Benzoylphenylacetylene.....	25	28.403	(17)
$C_{15}H_{18}O_2$	Octyl benzoate.....	15	19.992	(18)
$C_{15}H_{20}O_2$	Cetyl acetate.....	20	18.76	(18)
$C_{18}H_{16}$	Triphenylmethane.....	15	36.011	(18)
$C_{20}H_{22}N_2O_2$	Nitrocamphor anhydride§ †††.....	14.9	19.712	(19)

\* Value for  $\lambda_{Hg} = 5461 \text{ \AA}$ .† Dissolved in ethyl alcohol,  $C = 10.215\%$  by weight.‡ Dissolved in ethyl alcohol,  $C = 11.57\%$  by weight.

§ Dissolved in ethylene chloride.

||  $C = 100/7 = 14.3M\%$ .¶  $C = 10M\%$ .\*\*  $C = 25M\%$ .††  $C = 20M\%$ .†††  $C = 200/7 = 28.6M\%$ .§§  $C = 100/3 = 33.3M\%$ .|||  $C = 400/7 = 57.1M\%$ .¶¶ Dissolved in  $CCl_4$ ;  $C = 100/1.517 = 65.9M\%$ .\*\*\*  $C = 100/6 = 16.7M\%$ .†††  $C = 100/21 = 4.76M\%$ .

TABLE 10.—SPECIFIC MAGNETIC ROTATORY POWER OF SOLUTIONS

For Verdet constant for solutions, see Tables 6 and 7.  $[\omega]_S = (1 + 1000\Delta)\{\tau_1[\omega]_1 + \tau_2[\omega]_2\}$ ;  $\tau_2[\omega]_2 = \{[\omega]_S - \tau_1[\omega]_1\}$ . If  $V_c = V_1[1 + a\tau_2 + b\tau_2^2]$ ,  $0 < \tau_2 < 1$ ,  $\delta = \max.$  deviation of  $V_c$  from observed  $V$  for the solution;  $V_1 =$  Verdet's constant for constituent No. 1.  $R = [\omega]_2/[\omega]''$ , where  $[\omega]'' =$  value for water at same temperature. Temperature  $25^\circ C$ ,  $\lambda = 5893 \text{ \AA} = D$ -line; unit of  $d = 1 \text{ g per ml}$ .

Water—Acetic acid ( $C_2H_4O_2$ ) (32)

$100\tau_2$	$d$	$R$
12.868	1.0111	0.763
30.444	1.0364	0.798
48.577	1.0534	0.743
66.640	1.0637	0.750
97.120	1.0437	0.744

Water—Ethyl alcohol ( $C_2H_6O$ ) (31)

$100\tau_2$	$d$	$\Delta$
0	0.9971	0
7.542	0.9840	3.3
14.94	0.9735	1.0
20.43	0.9659	0
30.04	0.9507	0.6
41.59	0.9273	7.0
50.33	0.9092	6.6
62.76	0.8807	2.8
69.54	0.8648	5.5
79.40	0.8390	6.4
88.90	0.8167	7.7
100.00	0.7835	0

 $H_2O-HCl$  (32)

$100\tau_2$	$d$	$R$
$a = 1.880; b = 0; \delta = 0.2\%$		
14.319	1.0661	2.209
20.697	1.0977	2.178
25.568	1.1243	2.164
$t = 20^\circ C$ (25)		
15.63	1.0758	2.196
25.60	1.1274	2.172
30.86	1.1564	2.120
36.50	1.1846	2.096
41.70	1.2051	2.008
100.00	0.8240	1.076

 $H_2O-H_2SO_4$  (32)

$100\tau_2$	$d$	$\Delta$
18.972	1.1308	0.337
36.327	1.2693	0.347
62.553	1.5205	0.366
80.130	1.7304	0.392
97.717	1.8310	0.407

$100\tau_2$	$d$	$\Delta$
$t = 15^\circ$ (25)		
0	1.00000	0
9.179	1.06305	-6.8
11.154	1.07706	-8.3
14.019	1.09785	-11.2
18.921	1.13464	-14.9
28.005	1.20620	-22.0
35.165	1.26529	-28.2
47.407	1.37413	-41.9
57.938	1.47966	-41.8
64.413	1.55074	-44.1
72.998	1.65021	-42.7
84.349	1.77753	-31.6
93.663	1.83617	-15.2
96.598	1.84264	-3.7
100.000	1.83840	0

 $H_2O-KCl$  (32)

$100\tau_2$	$d$	$R$
$a = 1.08; b = 0; \delta = 0.7\%$		
10.345	1.0724	1.282
19.143	1.1240	1.333
25.830	1.1833	1.270

 $H_2O-LiCl$  (32)

$100\tau_2$	$d$	$R$
$a = 1.807; b = 0; \delta = 1.9\%$		
10.677	1.0623	2.076
21.102	1.1373	2.109
29.443	1.1818	1.991
31.504	1.2044	1.982
36.356	1.2285	1.928
40.755	1.2729	1.888
43.328	1.2894	1.860

 $H_2O-NH_4NO_3$  (32)

$100\tau_2$	$d$	$R$
$a = 0.148; b = 0; \delta = 0.36\%$		
10.485	1.0398	0.489
12.096	1.0412	0.507
20.589	1.0831	0.487
27.553	1.1142	0.504
49.378	1.2237	0.503
62.030	1.2869	0.526

 $H_2O-NaCl$  (32)

$100\tau_2$	$d$	$R$
$a = 1.473; b = 0; \delta = 0.5\%$		
11.410	1.0882	0.558
18.300	1.1318	1.604
24.292	1.1794	1.606



Chloroform (CHCl<sub>3</sub>)—Acetone (C<sub>3</sub>H<sub>6</sub>O) (31)

100τ <sub>2</sub>	d	Δ
0	1.4783	0
10.95	1.3498	+ 1.2
22.53	1.2349	+ 6.1
29.04	1.1783	- 1.1
40.77	1.0878	+ 2.9
52.43	1.0113	0.0
58.82	0.9729	- 7.0
71.03	0.9086	-16.2
78.56	0.8727	-1.6
85.25	0.8436	- 8.7
100.00	0.7856	0

Carbon tetrachloride (CCl<sub>4</sub>)—Benzene (C<sub>6</sub>H<sub>6</sub>) (31)

100τ <sub>2</sub>	d	Δ
0.00	1.5839	0
9.96	1.4651	10.5
18.03	1.3809	7.4
29.33	1.2785	11.0
42.73	1.1750	13.9
51.06	1.1188	16.9
59.32	1.0642	14.6
68.19	1.0186	+ 9.5
79.67	0.9960	-24.2
89.35	0.9172	+ 9.2
100.00	0.8736	0

Ethylene chloride (C<sub>2</sub>H<sub>4</sub>Cl<sub>2</sub>)—Benzene (C<sub>6</sub>H<sub>6</sub>) (31)

100τ <sub>2</sub>	d	Δ
0.00	1.2492	0
11.90	1.1860	- 4.7
20.79	1.1441	+ 3.3
26.31	1.1193	+ 8.2
34.25	1.0858	+ 1.7
49.23	1.0280	+ 6.0
58.01	0.9971	+ 2.0
67.87	0.9647	+ 3.7
77.21	0.9361	+ 6.3
86.37	0.9097	+ 4.4
100.00	0.8736	0

Ethyl alcohol (C<sub>2</sub>H<sub>5</sub>O)—Aniline (C<sub>6</sub>H<sub>7</sub>N) (32)a = 1.25; b = 1.06; δ = 2.5% if τ<sub>2</sub> > 0.29

100τ <sub>2</sub>	d	Δ
0.000	0.7865	0
9.805	0.8083	-13.5
20.485	0.8317	-33.4
29.707	0.8524	-26.8
36.370	0.8673	-31.6
50.878	0.9003	-30.0
59.609	0.9206	-38.8
71.458	0.9483	-26.3
80.992	0.9713	-21.9
88.728	0.9893	-16.3
100.00	1.0174	0

Benzene (C<sub>6</sub>H<sub>6</sub>)—Aniline (C<sub>6</sub>H<sub>7</sub>N) (32)

100τ <sub>2</sub>	d	Δ
0.000	0.8725	0
11.893	0.8886	7.3
22.102	0.9026	4.6
34.378	0.9202	2.8
40.177	0.9284	4.2
52.061	0.9459	+ 0.4
61.486	0.9598	- 3.1
71.607	0.9747	+ 1.6
80.972	0.9889	3.6
88.176	0.9997	4.2
100.000	1.0174	0

TABLE 11.—DISPERSION OF VERDET CONSTANT: FORMULAE

For dispersion formulae for gases, see Table 2

$$V = \frac{C}{\lambda} \left( n - K \lambda \frac{dn}{d\lambda} \right); \text{ visible spectrum (14)}$$

$$V = \frac{C_1}{n\lambda^2} \left[ \left( \frac{\lambda^2}{\lambda^2 - \lambda_1^2} \right)^2 + K_1 \right]; \text{ visible and ultra-violet (21); } n = \text{index of refraction}$$

Unit of λ, λ<sub>1</sub> = 0.001 mm = 1μ = 10<sup>4</sup> Å; K and K<sub>1</sub> are dimensionless

	K	Lit.
Creosote.....	35	(13)
Glass:*		
Crown.....	28.90	(13)
Flint (1).....	8.01	(13)
Flint (2).....	9.20	(13)
Flint (3).....	13.03	(13)
Fe <sub>2</sub> Cl <sub>6</sub> †.....	-122	(1)

	K	λ <sub>1</sub>	K <sub>1</sub>	Lit.
NaCl‡.....	26.39			(14)
TiCl <sub>4</sub> .....	-715.82			(2)
H <sub>2</sub> O.....	77.65	0.12604	0.7381	(21, 23)
CS <sub>2</sub> .....	15	0.1804	0	(14, 21)
C <sub>6</sub> H <sub>6</sub> .....		0.1902	0.6069	(21)
m-C <sub>8</sub> H <sub>10</sub> .....		0.1886	0.64219	(21)
α-C <sub>10</sub> H <sub>7</sub> Br.....		0.2563	1.1265	(21)

\* For crown, d = 2.55; flint (1), (2), (3), d = 5.32, 4.39, 4.08, respectively.

† Aqueous solution, 33% Fe<sub>2</sub>Cl<sub>6</sub>.

‡ Range covered is 0.214μ ≤ λ ≤ 0.644μ.

TABLE 12.—DISPERSION OF VERDET CONSTANT FOR PURE GASES

For dispersion formulae, see Table 11. Temperature (t) in °C; Unit of λ = 1 Å, p = 1A<sub>m</sub>

λ	O <sub>2</sub> (30)			H <sub>2</sub> (30)			CO <sub>2</sub> (30)		
	t	p	V/V <sub>1</sub>	t	p	V/V <sub>1</sub>	t	p	V/V <sub>1</sub>
4358	17.4	83.8	1	18.6	93.85	1			
4047	17.2	83.8	1.10	18.3	93.9	1.18	16.1	25.35	1
3665	17.5	83.25	1.31	18.7	90.0	1.45	17.5	27.3	1.22
3130	16.9	84.9	1.795	17.9	88.1	2.14	17.5	27.3	1.79
2805	17.4	82.5	2.24	19.8	75.2	2.83	17.2	27.2	2.27
2755	17.1	41.3	2.31						
2654	16.5	41.05	2.50	19.7	75.5	3.29	16.5	27.2	2.61
2535				20.9	74.9	3.67	16.2	27.3	2.95
2482				20.5	75.0	3.905			
2399				19.3	74.7	4.27			
2378				19.3	74.8	4.37			

TABLE 13.—DISPERSION OF VERDET CONSTANT: PURE SUBSTANCES

See also Table 14. For dispersion formulae, see Table 11

Unit of λ = 1mμ = 10 Å; λ<sub>D</sub> = 589.3mμ = 5893 Å

N <sub>2</sub> * (10); t = -195.5°C		O <sub>2</sub> * (10); t = -182.5°C	
λ	V/V <sub>D</sub>	λ	V/V <sub>D</sub>
6260	0.871	6260	0.897
6100	0.935	6100	0.848
5780	1.043	5780	1.062
5461	1.172	5461	1.103
5010	1.355	5010	1.118
4359	1.860	4359	1.319

\* Liquid.



CO <sub>2</sub> * (8); <i>t</i> = 26°C		C <sub>4</sub> H <sub>10</sub> O, Isobutyl alcohol (25)		C <sub>10</sub> H <sub>16</sub> , Limonene (10)		C <sub>10</sub> H <sub>17</sub> Cl, Pinene hydrochloride	
λ	V/V <sub>D</sub>	λ	V/V <sub>D</sub>	λ	V/V <sub>D</sub>	λ	V/V <sub>D</sub>
6260	0.866	546.1	1.174	656	0.79	(10)	
5461	1.200	436.0	1.923	578	1.04	656	0.79
4359	2.130			546	1.18	578	1.04
CS <sub>2</sub> * (21)		C <sub>5</sub> H <sub>10</sub> O <sub>2</sub> , Isovaleric acid (25)				546	1.17
670.8	0.72572	546.1	1.176	436	1.97	436	1.95
495.8	1.5432	436.0	1.917				
432.6	2.2407	C <sub>6</sub> H <sub>6</sub> , Benzene (21)		C <sub>10</sub> H <sub>16</sub> , Limonene (active) (11)		C <sub>10</sub> H <sub>15</sub> O, Borneol (10)	
414.4	2.5377	452.9	1.8785	710.0	0.707	656	0.79
404.6	2.7206	404.6	2.5301	546.1	1.182	578	1.04
(25)		363.1	3.4541	491.6	1.507	546	1.17
546.1	1.197	330.6	4.6650	435.9	1.993	492	1.48
436.0	2.140	310.0	5.8680			436	1.945
CS <sub>2</sub> (8)		C <sub>6</sub> H <sub>10</sub> O <sub>5</sub> , Dimethyl malate		C <sub>10</sub> H <sub>16</sub> , α-Pinene (10)		C <sub>10</sub> H <sub>18</sub> O, Citronellal (active)	
626.0	0.863	(active) (11)		656	0.795	(11)	
578.0	1.170	710.0	0.707	578	1.04	710.0	0.661
546.1	1.221	546.1	1.192	546	1.175	546.1	1.174
435.9	2.190	491.6	1.468	492	1.48	491.6	1.475
H <sub>2</sub> O, see Table 1		435.6	1.856	436	1.94	435.6	1.916
SO <sub>2</sub> * (8); <i>t</i> = -10°C		C <sub>6</sub> H <sub>12</sub> O <sub>2</sub> , Methyl valerate				C <sub>10</sub> H <sub>18</sub> O, Menthone (active)	
6260	0.910	(active) (11)		C <sub>10</sub> H <sub>16</sub> , β-Pinene (10)		(11)	
6100	0.942	710.0	0.670	656	0.79	710.0	0.691
5461	1.151	546.1	1.184	578	1.04	546.1	1.181
4359	1.795	491.6	1.467	492	1.49	491.6	1.450
TiCl <sub>4</sub> , Titanium tetrachloride;		435.9	1.849	436	1.97	435.9	1.937
see Table 4		C <sub>6</sub> H <sub>14</sub> , Hexane (10)		366	3.09		
CH <sub>3</sub> Cl, Methyl chloride (8)		656	0.78	313	4.31	C <sub>10</sub> H <sub>18</sub> O, Pinene hydrate (10)	
<i>t</i> = 18°C		578	1.04	C <sub>10</sub> H <sub>16</sub> , Turpentine (active)		656	0.79
626.0	0.897	546	1.175	(11)		578	1.04
546.1	1.168	492	1.48	710.0	0.655	546	1.18
435.9	1.957	436	1.93	546.1	1.179	492	1.48
CH <sub>4</sub> O, Methyl alcohol (10)		C <sub>8</sub> H <sub>10</sub> , <i>m</i> -Xylene (21)		491.6	1.503	436	1.95
656	0.81	670.8	0.75117	435.9	1.961	404	2.33
578	1.04	495.8	1.5034	C <sub>8</sub> H <sub>14</sub> O <sub>5</sub> , Diethyl malate (11)		366	2.98
546	1.155	452.9	1.8738	(active)		313	4.30
492	1.47	404.6	2.5227	710.0	0.666	280	5.75
436	1.915	363.1	3.4285	546.1	1.173	265	6.60
366	2.80	C <sub>10</sub> H <sub>14</sub> O, Carvone (active) (11)		435.9	1.915	253	7.68
334	3.45	710.0	0.715			C <sub>10</sub> H <sub>18</sub> O <sub>6</sub> , Dipropyl tartrate	
254	7.3	546.1	1.168	C <sub>10</sub> H <sub>16</sub> O, Camphor (10)		(active) (11)	
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> , Acetic acid (25)		491.6	1.526	656	0.80	710.0	0.680
546.1	1.175	C <sub>8</sub> H <sub>14</sub> O <sub>6</sub> , Diethyl tartrate		578	1.04	546.1	1.173
436.0	1.924	(active) (11)		546	1.17	491.6	1.442
C <sub>3</sub> H <sub>6</sub> O, Acetone (25)		710.0	0.670	492	1.505	435.9	1.899
546.1	1.481	546.1	1.158	436	1.94	CCl <sub>4</sub> , Carbon tetrachloride (25)	
436.0	1.942	453.9	1.895	366	2.95	546.1	1.182
C <sub>3</sub> H <sub>8</sub> O, <i>n</i> -Propyl alcohol (25)		C <sub>10</sub> H <sub>7</sub> Br, α-Bromonaphthalene		334	3.66	436.0	1.948
546.1	1.192	(21)		254	7.7		
436.0	1.946	670.8	0.74025	C <sub>10</sub> H <sub>16</sub> O, Pulegone (active) (11)			
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub> , Isobutyric acid (25)		495.8	1.6035	710.0	0.681		
546.1	1.162	452.9	2.1062	546.1	1.185		
436.0	1.930	404.6	3.1205	491.6	1.482		
C <sub>4</sub> H <sub>10</sub> O, Ethyl ether (10)		373.5	4.4230				
656	0.80						
578	1.04						
546	1.165						
492	1.47						
436	1.91						

\* Liquid.



TABLE 14.—DISPERSION OF VERDET CONSTANT: PURE ORGANIC SUBSTANCES (16)

Cf. Table 13; numbers in body of table are values of  $V/V_{H_2}$ ;  $\lambda_{H_2} = 5461 \text{ \AA}$ 

Formula	Name	$\lambda = 6708$	6438	5893	5086	4800	4678	4359- $\lambda$
CS <sub>2</sub>	Carbon disulfide	0.624	0.686	0.836	1.190	1.376	1.464	1.764
CH <sub>2</sub> O <sub>2</sub>	Formic acid	0.647	0.708	0.852	1.164	1.322		1.635
CH <sub>4</sub> O	Methyl alcohol	0.645	0.707	0.851	1.164	1.315	1.386	1.624
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Acetic acid	0.648	0.698	0.851	1.163	1.331		1.631
C <sub>2</sub> H <sub>6</sub> O	Ethyl alcohol	0.638	0.708	0.849	1.166	1.318	1.393	1.626
C <sub>3</sub> H <sub>6</sub> O	Allyl alcohol	0.641	0.700	0.847	1.177	1.332		1.672
C <sub>3</sub> H <sub>8</sub> O <sub>2</sub>	Propionic acid	0.648	0.711	0.856	1.165	1.320		1.635
C <sub>3</sub> H <sub>8</sub> O	<i>n</i> -Propyl alcohol	0.642	0.713	0.850	1.163	1.321		1.629
C <sub>3</sub> H <sub>8</sub> O	Isopropyl alcohol	0.642	0.702	0.850	1.163	1.320		1.634
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	<i>n</i> -Butyric acid	0.645		0.853				1.634
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Isobutyric acid	0.646		0.849				1.633
C <sub>4</sub> H <sub>10</sub> O	<i>n</i> -Butyl alcohol	0.649	0.707	0.849	1.168	1.328		1.637
C <sub>4</sub> H <sub>10</sub> O	Isobutyl alcohol	0.648	0.699	0.846	1.162	1.321		1.635
C <sub>4</sub> H <sub>10</sub> O	<i>sec.</i> -Butyl alcohol	0.645	0.713	0.850	1.164	1.309	1.391	1.635
C <sub>4</sub> H <sub>10</sub> O	<i>tert.</i> -Butyl alcohol	0.643	0.704	0.852	1.166	1.328		1.645
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Isovaleric acid	0.651	0.702	0.848	1.165	1.324		1.636
C <sub>5</sub> H <sub>12</sub> O	Isoamyl alcohol	0.650	0.709	0.852	1.169	1.325		1.634
C <sub>6</sub> H <sub>12</sub> O	<i>act.</i> -Amyl alcohol	0.647		0.850				1.641
C <sub>6</sub> H <sub>12</sub> O	<i>sec.</i> -Amyl alcohol	0.651		0.852				1.636
C <sub>6</sub> H <sub>12</sub> O	<i>tert.</i> -Amyl alcohol	0.651	0.703	0.852	1.165	1.325		1.643
C <sub>6</sub> H <sub>14</sub>	<i>n</i> -Hexane	0.647	0.710	0.851	1.168	1.318		1.636
C <sub>6</sub> H <sub>14</sub> O	Methylisobutyl carbinol	0.650		0.850				1.644
C <sub>6</sub> H <sub>14</sub> O	<i>sec.</i> -Hexyl alcohol	0.647	0.705	0.852	1.165	1.321		1.639
C <sub>7</sub> H <sub>16</sub> O	<i>n</i> -Heptyl alcohol	0.644	0.708	0.855	1.162	1.320		1.635
C <sub>7</sub> H <sub>16</sub> O	<i>sec.</i> -Heptyl alcohol	0.648		0.849				1.639
C <sub>8</sub> H <sub>10</sub> O	Phenylmethyl carbinol	0.624	0.685	0.839	1.184	1.363		1.739
C <sub>8</sub> H <sub>18</sub>	<i>n</i> -Octane	0.650	0.706	0.850	1.168	1.325		1.634
C <sub>8</sub> H <sub>18</sub> O	<i>n</i> -Octyl alcohol	0.647	0.705	0.851	1.166	1.320		1.636
C <sub>8</sub> H <sub>18</sub> O	<i>sec.</i> -Octyl alcohol	0.642	0.705	0.849	1.163	1.320	1.394	1.635
C <sub>9</sub> H <sub>12</sub> O	Phenylethyl carbinol	0.634	0.689	0.835	1.181	1.362	1.451	1.731
C <sub>9</sub> H <sub>20</sub> O	Methylheptyl carbinol	0.649		0.849				1.635
C <sub>9</sub> H <sub>20</sub> O	Ethylhexyl carbinol	0.644	0.703	0.853	1.165	1.322		1.634
C <sub>10</sub> H <sub>22</sub> O	Methyloctyl carbinol	0.642		0.848				1.636
C <sub>11</sub> H <sub>24</sub> O	Methylnonyl carbinol	0.645		0.848				1.638
C <sub>12</sub> H <sub>26</sub> O	Methyldecyl carbinol	0.644		0.849				1.639

TABLE 15.—DIFFERENTIAL LAG IN APPEARANCE OF FARADAY EFFECT (1)

If  $l/l_0$  = time that elapses between the application of the field and the appearance of the rotation in the substance [in CS<sub>2</sub>],  $\Delta \equiv l - l_0$ . Unit of  $\Delta = 1 \text{ m}\mu \text{ sec} = 10^{-9} \text{ sec}$ ; uncertainty in  $\Delta \equiv \pm 0.3 \text{ m}\mu \text{ sec}$ .

Substance	$\Delta$
CS <sub>2</sub> Carbon disulfide	0
H <sub>2</sub> O Water	1.1
CCl <sub>4</sub> Carbon tetrachloride	1.1
C <sub>6</sub> H <sub>6</sub> Benzene	1.9
C <sub>8</sub> H <sub>10</sub> Xylene	2.1
CHCl <sub>3</sub> Chloroform	2.4
C <sub>7</sub> H <sub>8</sub> Toluene	2.5
C <sub>5</sub> H <sub>12</sub> O Amyl alcohol	4.0
CHBr <sub>3</sub> Bromoform	4.1

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(For a key to the periodicals see end of volume)

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## ROTATION AT REFLECTION—KERR EFFECT

A. COTTON AND M. CAU

## CONTENTS

Polar reflection, normal incidence.....	435
Polar reflection, oblique incidence.....	438
Longitudinal reflection, oblique incidence.....	438
Transverse reflection, oblique incidence.....	438

When plane polarized light is incident upon a reflecting surface, magnetizing the reflecting material produces, in general, a rotation of the plane of polarization of the reflected light, and under certain conditions introduces a circularly polarized component. The magnitudes of the several effects depend upon the intensity of magnetization ( $I$ ) of the substance and apparently not upon either the temperature or the intensity of the magnetic field ( $H$ ), except as these affect  $I$ ; they vary from specimen to specimen, and not

infrequently depend upon the particular region under study. Three cases are distinguished: (1) Polar reflection,  $I$  being normal to the reflecting surface; (2) longitudinal (or meridional) reflection,  $I$  being parallel to reflecting surface and to the plane of incidence; (3) transverse (or equatorial) reflection,  $I$  being parallel to reflecting surface and perpendicular to plane of incidence. If  $r$  = rotation produced by increasing the magnetization from zero to  $I$ , then for polar reflection, normal incidence,  $r = KI$ , where  $K$  depends only upon the reflector and the wave-length ( $\lambda$ ) of the light;  $K$  is Kerr's constant;  $r$  is considered positive if it is in the direction of the Amperian currents producing  $I$ .

When a key number precedes the symbol or name of a substance it refers to Table 1 where such information as is available regarding the specimen is given.

TABLE 1.—KERR CONSTANT ( $K_\lambda$ ) AND ROTATION ( $r_m$ ) AT SATURATION: POLAR REFLECTION, NORMAL INCIDENCE, ONE WAVE-LENGTH  
 $H$  = intensity of magnetic field; the substance is magnetically saturated (= satd.) unless marked "uns."; unit of  $\lambda = 1 \text{ m}\mu = 10^{-6} \text{ mm} = 10 \text{ \AA}$ ; of  $K_\lambda = 0.001$  minute of arc per egsm unit of  $I$ ; of  $r_m = 1'$ ; of  $H = 1$  kilogauss = 1000 gauss

Key	Substance	Remarks	Source	$H$	$\lambda$	$K_\lambda$	$r_m$	Lit.
1	Fe	Electrolytic iron.....	Gumlich	40	530.0	-13.5	-22.68	(1)
2	Fe	Electrolytic, on platinized glass.....		13	520		-11.4	(13)
3	Fe	Cathode deposit (vacuum).....		13.2	520		-7.8	(13)
4	Fe	Distilled on glass, brilliant.....		20.5	588		-18.1	(2)
5	Fe	Distilled on glass, dull.....		15.8	588		-17.9	(2)
6	Fe	Pure.....	Kahlbaum	22.9	520		-19.74	(3)
7	Fe	Pure cast; no S, Si, Mn.....	Weiss		530.0	-11.3	-18.97	(1)
8	Fe	Swedish; 0.22 % C; tr. of P, Si, Mn.....	Kohlswa	40	546.1	-12.3	-20.59	(1)
9	Fe	Swedish commercial.....		20.4	520		-19.2	(3)
10	Fe, Ce	Ferrocerium.....		uns.	530		-6.22*	(9)
11	Fe <sub>2</sub> O <sub>3</sub> .FeO	Magnetite.....	Griesheim	satd.	450.0	-4.6	-1.89	(1)
12	Fe <sub>2</sub> O <sub>3</sub> .FeO	Magnetite; artificial, compressed powder.....	Weiss	satd.	450.0	-2.7	-1.10	(1)
13	Fe <sub>2</sub> O <sub>3</sub> .FeO	Magnetite; natural.....	DuBois	12	450.0	-5.2	-2.00	(1)
14	Fe <sub>2</sub> O <sub>3</sub> .FeO	Magnetite (Pfischthal).....		16.4	440		-1.44	(3)
15	Fe <sub>2</sub> O <sub>3</sub> .FeO	Magnetite (Traversella).....		15.8	439		-2.1†	(2)
16	Fe <sub>2</sub> O <sub>3</sub> .FeO	Magnetite.....		10	900		+3	(4)
17	Fe <sub>2</sub> O <sub>3</sub> .ZnO	Franklinite.....	DuBois	7.5	450.0	-8.0	-1.19	(1)
18	Fe <sub>2</sub> O <sub>3</sub> .ZnO	Franklinite (New Jersey).....		satd.	530		+1.2	(10)
19	Fe <sub>2</sub> O <sub>3</sub> .CuO	Cuproferrite.....	DuBois	7.5	477.0	+6.3	+1.68	(1)
20	Fe <sub>2</sub> O <sub>3</sub> .CuO	Cuproferrite.....	Hilpert	10.15	477		+1.75	(8)
21	Fe <sub>2</sub> O <sub>3</sub> .CoO	Cobalt ferrite.....	Hilpert	satd.	530		-0.6	(10)
22	Fe <sub>2</sub> O <sub>3</sub> .CaO	Calcium ferrite.....	Hilpert	satd.	530		+0.2	(10)
23	Fe <sub>7</sub> S <sub>8</sub>	Pyrrhotite (Brazil).....		satd.	Any		+1	(9)
24	Fe <sub>3</sub> C	Cementite.....	Hilpert	satd.	530		-26.45	(9)
25		Steel.....	Schmidt and Haensch	20	588		-22.7	(2)
26		Steel.....		19.2	520		-20.88†	(3)
27	Fe <sub>2</sub> Si	Ferrosilicon; Fe <sub>2</sub> Si = 30 At. %§.....	Tammann	satd.	530		-16.75	(10)
28	Fe <sub>2</sub> Co		Weiss	20	530.0	-14.95	-27.64	(1)
29	Fe, Co, Sb	66Fe + 30Co + 4Sb.....	DuBois	satd.	530.0	-14.7	-23.66	(1)
30	Fe, Ni	25.4 % Ni.....	Krupp	16.3	589		-17.29*	(8)
31	Fe, Ni	27 % Ni.....	Weiss	16.8	589		-15.92*	(8)
32	Fe <sub>2</sub> Ni	36 % Ni.....	Weiss	20	530.0	-17.2	-15.05	(1)
33	Fe, Ni	36 % Ni (Invar).....	Commentry-Fourchambault	14.5	574	-15.6	-13.65	(8)
34	Fe, Ni	36 % Ni (Invar).....	De Haën	19.8	520		-13.86	(3)
35	Fe, Mn	92.2Fe + 7.8Mn.....	Gumlich	39	530.0	-14.8	-19.70	(1)
36	Fe, Mn	89.6Fe + 10.4Mn.....	Gumlich	satd.	530.0	-15.1	-13.16	(1)
37	Co	Electrolytic.....	Merck	34	530.0	-14.7	-20.58	(1)
38	Co	Pure.....	Kahlbaum	22.1	520		-21.18	(3)



TABLE 1.—(Continued)

Key	Substance	Remarks	Source	H	$\lambda$	$K_\lambda$	$r_m$	Lit.
39	Co	Unspecified.....		18.4	588		-20.8	(2)
40	Co, Sb	88Co + 12Sb.....	Pr. Merrett	satd.	530.0	-16.2	-18.72	(1)
41	Co, Si	98Co + 2Si.....	Pr. Merrett	satd.	530.0	-18.8	-20.52	(1)
42	Co, Sn	93.2Co + 6.8Sn.....	Pr. Merrett	23	530.0	-12.7	-14.30	(1)
43	Co, Cr	87Co + 13Cr.....	Pr. Merrett	satd.	530.0	-15.6	-13.72	(1)
44	Co, Cr, Ni	83Co + 15Cr + 2Ni.....	Tammann	satd.	530.0	-11.6	-8.96	(1)
45	Ni	Cast in N <sub>2</sub> .....	Merck	20	590.0	-15.4	-7.85	(1)
46	Ni	Distilled on glass.....		15.8	588		-6.5	(2)
47	Ni	Pure.....	Pr. Merrett	20	530.0	-15.7	-8.05	(1)
48	Ni	Pure.....	Kahlbaum	20.5	520		-7.74	(3)
49	Ni	Unspecified.....		17.7	588		-8.3	(2)
50	Mn, As	42.5Mn + 57.5As.....	Hilpert	satd.	589(?)		-1.5	(10)
51	Mn, Sb	35Mn + 65Sb.....	Tammann	satd.	530		-20.46	(10)
52	Mn, Bi	20.5Mn + 79.5Bi.....	Hilpert	satd.	530		+1.48	(9)
53	Mn, Sn	65Mn + 35Sn.....	Tammann	satd.	530		-2.00	(9)
54	MnB	Manganese boride.....	Hilpert	satd.	589(?)		< 0.3¶	(9)
55	Mn, Cu, Al	58.9Cu + 26.5Mn + 14.6Al (Heusler alloy).		16.8	588		-2.3	(2)

\* Not saturated; H = 14 to 16 kilogauss.

† Reflecting surface is parallel to face of octahedron.

‡ Quenched.

TABLE 2.—DISPERSION OF ROTATION ( $r_m$ ) AT SATURATION: POLAR REFLECTION, NORMAL INCIDENCE

The key numbers refer to Table 1 where the material is more fully defined; H = intensity of magnetic field; satd. = saturated; unit of  $\lambda = 1 \text{ m}\mu = 10^{-6} \text{ mm} = 10 \text{ \AA}$ ; of  $r_m = 1'$ .

1 Fe (1); H = 36.56

$\lambda$	$r_m$
442.5	-16.70
457.4	-17.40
474.0	-18.27
492.5	-19.32
515.5	-20.79
531.5	-22.54
538.5	-23.31
546.1	-23.73
557.5	-24.57
571.5	-25.34
599.0	-26.33
628.0	-27.20
650.0	-27.65
690.0	-28.56

2, 3, 4, 5, 6 Fe, see Table 3

8 Fe (1); H = 39.7

435.0	-14.66
442.5	-14.95
457.4	-15.55
492.5	-17.61
515.5	-19.15
531.5	-20.14
538.5	-20.55
546.1	-20.93
546.1	-20.59*
571.5	-22.79
590.1	-25.13*
599.0	-24.33
650.0	-27.47
690.0	-29.75

9 Fe, see Table 3

10 Fe, Ce† (9); unsaturated

$\lambda$	$r_m$
435	-5.09
466	-5.50
503	-5.97
530	-6.22
567	-6.41
615	-6.52
675	-6.60

11 Magnetite (10); satd.

$\lambda$	$r_m$
435	-2.91
450	-2.53
466	-2.17
483	-1.10
503	+0.70
530	+2.69
567	+4.27
589	+4.54
615	+4.44
675	+3.53
695	+3.14
712	+2.76
450	-1.89†
600	+3.83†

12 Magnetite (8); H = 18.88

$\lambda$	$r_m$
436	-4.40
453	-3.67
477	-1.56
510	+1.53
539	+3.11

12.—(Cont'd)

$\lambda$	$r_m$
589	+4.80
637	+4.88
688	+4.54
450	-1.10†
600	+2.25†

13 Magnetite§ (8); H = 11.56

$\lambda$	$r_m$
436	-3.81
453	-1.52
464	0.00
477	+1.06
510	+3.07
539	+3.84
574	+4.45
599	+3.94
637	+3.32
688	+2.50
450	-2.00†
600	+3.20†

14, 15 Magnetite, see Table 3

16 Magnetite (4); H = ca. 10

$\lambda$	$r_m$
900	+3
1000	+1
1500	-3
2000	-4

17 Fe<sub>2</sub>O<sub>3</sub>.ZnO (1); H = 27.34

$\lambda$	$r_m$
442.5	-1.40
457.4	-1.26
474.0	-1.09
492.5	-0.65
515.5	0.00
531.5	+0.30

§ At. % = Atom %.

|| Yellow light,  $\lambda$  not stated.

¶ May be zero.

17.—(Cont'd)

$\lambda$	$r_m$
546.1	+0.42
557.5	+0.78
571.5	+0.92
599.0	+0.98
628.0	+1.05
650.0	+1.12
690.0	+1.19

18 Fe<sub>2</sub>O<sub>3</sub>.ZnO (10); satd.

$\lambda$	$r_m$
450	-1.8
466	-1.0
483	+0.6
530	+1.2
567	+0.8
654	-0.3

20 Fe<sub>2</sub>O<sub>3</sub>.CuO (8); H = 10.15

$\lambda$	$r_m$
436	+1.31
477	+1.75
539	+1.28
574	+0.41
599	-0.36
637	-0.95
688	-0.78

21 Fe<sub>2</sub>O<sub>3</sub>.CoO (10); satd.

$\lambda$	$r_m$
450	-2.0
475	-0.7
503	-0.4
530	-0.6
589	-1.2
615	-1.5
654	-2.2

22 Fe<sub>2</sub>O<sub>3</sub>.CaO (10); satd.

$\lambda$	$r_m$
435	-0.3
475	-0.5
503	-0.1
530	+0.2
567	+0.1
589	-0.2
675	-0.5

24 Fe<sub>2</sub>C (9); satd.

$\lambda$	$r_m$
435	-30.28
450	-30.00
466	-29.42
483	-28.48
503	-27.13
530	-26.45
567	-26.40
615	-26.66
675	-27.01

25, 26 Steel, see Table 3

26 Steel (5); H = 5.7

$\lambda$	$r_m$
600	-8.3
700	-9.8
800	-10.6
900	-11.2
1000	-11.5
1200	-11.2
1400	-10.4
1600	-9.3
1800	-8.4
2000	-7.9
2200	-7.4

26\* Steel (4); H = ca. 10

$\lambda$	$r_m$
800	-15.5
900	-16.0
1000	-16.0
1500	-12.5
2000	-10.5
2500	-9.5

27 Fe<sub>2</sub>Si (10); satd.

$\lambda$	$r_m$
435	-13.18
450	-14.22
483	-15.58
530	-16.75
567	-17.27
615	-17.65
675	-17.91
703	-18.05

28 Fe<sub>2</sub>Co (10); satd.

$\lambda$	$r_m$
435	-22.11
450	-21.7
466	-21.7
503	-24.05
530	-26.85
567	-29.94
615	-31.69
675	-33.33
695	-33.89

29 Fe, Co, Sb (1); H = 32.94

$\lambda$	$r_m$
442.5	-19.74
457.4	-20.33
474.0	-21.81
492.5	-23.24
515.5	-24.57
531.5	-25.65
546.1	-26.18
557.5	-26.81
571.5	-27.68
599.0	-29.43
628.0	-31.92
650.0	-32.30
690.0	-32.52



<b>30 Fe, Ni† (8);</b> <b>H = 14.4</b>		<b>37.—(Cont'd)</b>		<b>49.—(Cont'd)</b>		<b>2 Fe (13); H = 13</b>			<b>15.—(Continued)</b>		
$\lambda$	$r_m$	$\lambda$	$r_m$	$\lambda$	$r_m$	$\lambda$	$r_m$	$e$	$\lambda$	$r_m$	$e$
436	-10.63	599.0	-22.96	2000	+ 1.7	440	- 9.6	-0.06	588	+ 3.8	-0.93
510	-12.75	650.0	-23.68	2500	+ 2.4	480	-10.2	-0.23	623	+ 3.4	-1.52
589	-14.32	690.0	-24.25			520	-11.4	-0.42	656	+ 2.5	-1.83
637	-14.89	<b>38, 39 Co, see</b>		<b>51 Mn, Sb (10);</b>		560	-11.4	-0.45	<b>25 Steel (2); H = 20</b>		
688	-14.74	<b>Table 3</b>		<b>satd.</b>		600	-10.8	-0.50	439	-15.9	
<b>31 Fe, Ni† (8);</b>		<b>39 Co (4);</b>		435	-22.35	660	-10.8	-0.70	471	-17.1	-4.13
<b>H = 14.9</b>		<b>H = ca. 10</b>		466	-23.02	<b>3 Fe (13); H = 13.2</b>			505	-18.4	-4.32
436	-13.67	800	-11.3	483	-23.21	440	- 7.2		546	-20.5	-4.33
453	-13.88	900	-11.5	503	-23.19	480	- 7.2	-2.34	588	-22.7	-4.16
477	-14.66	1000	-11.1	530	-20.46	520	- 7.8	-2.20	623	-24.3	-3.98
510	-15.42	1500	- 9.0	567	-17.36	560	- 7.2	-2.12	656	-25.7	-3.80
589	-16.45	2000	- 8.0	615	-17.86	600	- 6.6	-2.16	<b>26 Steel † (3); H = 19.2</b>		
637	-16.19	2500	- 7.5	675	-18.75	660	- 9.0	-1.92	410	-16.20	-3.59
688	-16.25					680	- 7.8	-2.01	440	-17.10	-3.73
<b>32 Fe<sub>2</sub>Ni (10); satd.</b>		<b>45 Ni (1);</b>		<b>52 Mn, Bi (9); satd.</b>		<b>4 Fe (2); H = 20.5</b>			480	-18.78	-4.04
435	-17.56	<b>H = 31.40</b>		435	- 1.65	439	-12.6	-2.53	520	-20.88	-4.21
483	-19.88	442.5	- 8.31	450	- 1.00	471	-13.3	-2.66	560	-22.68	-4.23
530	-21.69	457.4	- 8.09	466	- 0.16	505	-14.3	-2.85	600	-24.30	-4.03
567	-22.55	474.0	- 7.80	483	+ 0.72	546	-16.2	-2.89	640	-26.28	-3.76
615	-20.30	492.5	- 7.52	503	+ 1.26	588	-18.1	-2.87	660	-26.70	-3.77
675	-19.33	515.5	- 7.32	530	+ 1.48	623	-19.9	-2.63	<b>34 Invar (3); H = 19.8</b>		
703	-20.00	531.5	- 7.21	567	+ 0.94	656	-20.9	-2.47	410	-13.14	-1.40
<b>33 Invar (8);</b>		538.5	- 7.21	615	+ 0.045	<b>5 Fe (2); H = 15.8</b>			440	-14.04	-1.15
<b>H = 13.36</b>		546.1	- 7.21	675	- 0.99	439	- 9.3	-4.79	480	-14.10	-0.80
436	-11.78	557.5	- 7.196	<b>53 Mn, Sn (9); satd.</b>		471	-10.3	-4.78	520	-13.86	-0.44
477	-12.48	571.5	- 7.40	435	- 2.24	505	-12.3	-4.81	560	-13.80	-0.17
539	-13.22	599.0	- 8.05	466	- 0.75	546	-15.2	-4.89	600	-13.32	0.00
574	-13.66	628.0	- 7.75	503	- 1.18	588	-17.9	-4.78	640	-13.62	+0.14
599	-13.74	650.0	- 8.076	530	- 2.00	623	-20.1	-4.52	660	-13.62	+0.23
637	-13.72	690.0	- 8.23	567	- 3.03	<b>6 Fe (3); H = 22.9</b>			<b>38 Co (3); H = 22.1</b>		
688	-13.54			615	- 4.26	410	-15.00	-3.73	410	-21.72	-1.79
<b>34 Invar, see Table 3</b>				675	- 5.52	440	-15.18	-3.88	440	-21.78	-1.68
<b>37 Co (1);</b>		<b>46, 48, 49 Ni, see</b>		<b>55 Heusler alloy, see</b>		480	-16.62		480	-21.12	-1.43
<b>H = 35.91</b>		<b>Table 3</b>		<b>Table 3</b>		520	-19.74	-4.56	520	-21.18	-1.33
442.5	-23.60	<b>49 Ni (4);</b>		<b>* Another specimen.</b>		560	-22.74	-4.60	560	-21.24	-1.23
457.4	-23.37	<b>H = ca. 10</b>		<b>† Not saturated.</b>		600	-24.78	-4.50	600	-21.48	-1.20
492.5	-22.80	800	- 7.0	<b>‡ Another specimen</b>		640	-26.58	-4.06	640	-22.02	-1.07
515.5	-22.45	900	- 5.0	<b>(1).</b>		660	-26.94	-4.12	660	-22.08	-1.08
531.5	-22.30	1000	- 4.0	<b>§ Reflecting surface is</b>		<b>9 Fe (3); H = 20.4</b>			<b>39 Co (2); H = 18.4</b>		
538.5	-22.30	1500	0.0	<b>parallel to face of octa-</b>		410		-4.29	439	-21.7	-1.595
546.1	-22.36			<b>hedron.</b>		440	-15.6	-4.58	471	-21.2	-1.334
571.5	-22.59					480	-16.8	-4.95	505	-20.9	-1.223
						520	-19.2	-5.27	546	-20.7	-1.135
						560	-20.4	-5.25	588	-20.8	-1.038
						600	-25.2	-5.02	623	-21.0	-0.857
						640	-26.4	-4.86	656	-21.4	-0.697
						660	-28.2	-4.65	<b>46 Ni (2); H = 15.8</b>		
						<b>14 Magnetite (3); H = 16.4</b>			439	- 7.3	-0.51
						410	- 4.26	+1.24	471	- 6.7	-0.25
						440	- 1.44	+1.71	505	- 6.6	-0.20
						480	+ 2.40	+1.00	546	- 6.4	-0.15
						520	+ 3.42	0.00	588	- 6.5	-0.05
						560	+ 4.62	-0.91	623	- 6.8	+0.04
						600	+ 3.54	-1.61	656	- 6.9	+0.12
						640	+ 2.58	-2.00	<b>48 Ni (3); H = 20.5</b>		
						660	+ 1.98	-1.60	410	-10.86	-0.97
						<b>15 Magnetite* (2); H = 15.8</b>			440	- 8.82	-0.65
						439	- 2.1	+1.19	480	- 7.74	-0.35
						471	+ 0.9	+1.11	520	- 7.74	-0.17
						505	+ 2.6	+0.37	560	- 8.28	-0.07
						546	+ 3.3	-0.19	600	- 8.64	+0.11

TABLE 3.—ELLIPTICITY PRODUCED BY MAGNETIZATION: POLAR REFLECTION, PLANE POLARIZED LIGHT INCIDENT NORMALLY, MAGNETIC SATURATION

Magnetizing the reflector not only rotates the plane of polarization, but also adds a weak component of circularly polarized light, making the reflected light elliptically polarized.  $E$  is numerically equal to ratio of the axes of the resultant ellipse; if direction of rotation of the circularly polarized component is same as that of the Amperian currents producing the magnetization,  $E$  is considered to be positive. The key numbers refer to Table 1 where the material is more fully defined.  $H$  = intensity of magnetic field;  $r_m$  = rotation corresponding to saturation, unit =  $1'$ ;  $e = 1000E$ ; unit of  $\lambda = 1 \text{ m}\mu = 10^{-6} \text{ mm} = 10 \text{ \AA}$ ; of  $H = 1$  kilogauss.



48.—(Continued)			55 Cu, Mn, Al (2); <i>H</i> = 16.8		
$\lambda$	$r_m$	$e$	$\lambda$	$r_m$	$e$
640	− 8.22	+0.23	439	+ 0.05	−0.66
660	− 8.40	+0.24	471	− 1.0	−0.64
49 Ni (2); <i>H</i> = 17.7			505	− 1.5	−0.64
439	− 9.3	−0.86	546	− 2.1	−0.42
471	− 8.9	−0.44	588	− 2.3	−0.20
505	− 8.2	−0.25	623	− 2.2	−0.10
546	− 8.1	−0.15	656	− 2.1	0.00
588	− 8.3	−0.04	* Reflecting surface is parallel to face of octahedron. † Quenched.		
623	− 8.5	+0.14			
656	− 8.7	+0.27			

TABLE 4.—POLAR REFLECTION, PLANE POLARIZED LIGHT, OBLIQUE INCIDENCE, Fe (11)

Filtered sunlight, sensibly homogeneous. No statement regarding composition and source of Fe, nor of the values of  $\lambda$ ,  $H$ , and  $I$ . Probably the Fe was magnetically saturated.  $i$  = angle of incidence.  $R_{||}$ [ $R_{\perp}$ ] = rotation when plane of vibration (electric vector) of incident light is parallel [perpendicular] to plane of incidence. If the plane of vibration of the incident light makes a characteristic angle  $\alpha_i$  with the plane of incidence, the reflected light is plane polarized and its plane of vibration makes an angle  $\alpha_r$  with plane of incidence. Angles are positive when measured in the direction of the Amperian currents which produce the field. Unit of  $i$  = 1°; of  $R_{||}$ ,  $R_{\perp}$ ,  $\alpha_i$  and  $\alpha_r$  = 1'.

$i$	$-2R_{  }$	$-2R_{\perp}$	$2\alpha_i$	$2\alpha_r$
6.0	33	33		
15.5	33	32.4		
22.2	33.5	31.2		
36.4	36	30		
44.3	45	28.8	−19.8	+57.2
56.9	52.8	24.6	−10.2	+57.1
68.1	51	19.2	+ 3.0	+44.8
76.6	45	12	+ 7.2	+36
84.8	15	6	+13.2	+20
87.2	6	1.5		
$i^*$	$-2R_{  }$	$-2R_{\perp}$	$\alpha_i$	$\alpha_r$
40.9	59.9	38	−46.8	+114.6
47.9	60.2	34	−29.4	+ 95.2
54.9	61.2	29.6	−16	+ 80
63.0	60.9	24.1	− 1.2	+ 61.9
67.8	59.2	20.5	+ 5.8	+ 54.8
72.8	51.6	16.3	+11.2	+ 47.4
76.6	38	11.9	+13.4	+ 39.4
82.6	12	5.2	+17.6	+ 29.2

\*  $H$  is greater than for data in above table.

TABLE 5.—LONGITUDINAL REFLECTION, PLANE POLARIZED LIGHT, OBLIQUE INCIDENCE

$I$  is parallel to surface and to plane of incidence. No statement regarding composition and source of Fe, nor of the values of  $\lambda$ ,  $H$ , and  $I$ . Probably the Fe was magnetically saturated. For notation, see Table 4. Three specimens.

Fe (12)			Fe.—(Continued)		
$i$	$2R_{  }$	$2R_{\perp}$	$i$	$2R_{  }$	$2R_{\perp}$
11	+ 2.3	−2.5	60	+11	−9
20	+ 4	−5	65	+ 8.7	
30	+ 6.7	−6.6	70	+ 6.5	−7.9
35	+ 7.6		75	+ 4.5	
40	+ 8	−6.7	78.9	0	−6.7
45	+ 9		80	− 1	
50	+10	−9	85	− 3	−3
55	+10.5				

Steel (7)			Ni, Electrolytic Ni on steel (7)		
$i$	$2R_{  }$	$2R_{\perp}$	$i$	$2R_{  }$	$2R_{\perp}$
19.0	+ 2.7	−4.8	20.0	0.0	
29.9	+ 7.3	−4.5	30.1	+ 1.8	−1.7
39.5	+ 7.7	−6.6	40.0	+ 1.4	−2.7
50.1	+ 6.9	−7.7	50.0	+ 0.3	−4.7
61.3	+ 7.5	−8.0	61.5	− 0.7	−4.2
65.0	+ 8.7	−9.4	65.3	− 2.2	−3.8
70.0	+ 8.1	−7.1	75.0	− 1.9	−1.1
75.0	+ 6.8	−6.0			
80.3	+ 2.6				
82.0	− 2.3	−4.3			
85.2	− 1.9	−3.9			

TABLE 6.—TRANSVERSE REFLECTION, PLANE POLARIZED LIGHT, OBLIQUE INCIDENCE (6)

$I$  is parallel to surface and perpendicular to plane of incidence. When  $I = 0$ , the intensity of that component of the reflected light which is polarized in plane of incidence is equal to that of the component polarized perpendicular thereto, if the plane of polarization of the incident light makes an angle  $\theta$  with the plane of incidence. When  $I$  is not zero, the equality occurs when the angle is  $\theta + \eta$ .  $i$  = angle of incidence. The key numbers refer to Table 1 where the material is more fully defined. Tabulated values =  $2\eta$ ; unit of  $\eta$  = 1'; of  $\lambda$  =  $1\text{m}\mu$  =  $10^{-6}\text{ mm}$  =  $10\text{ \AA}$ .

$\lambda$	590	730	910	$\lambda$	1210	1650	2100
$i$	26 Fe or steel			$i$	26 Fe or steel		
18.6	+ 3.77			19.8	+ 3.0	+ 0.4	0.0
19.6		+ 3.9	+ 4.3	41.9	+ 3.9	+ 0.5†	− 1.2*
40.9	+ 9.42*	+ 9	+11.0	66.8	+ 5.6†	+ 0.4	− 4.4
66.8	+17.80†	+16	+14.2	70		− 3.7	
74.6	+17.11	+15.7†	+12.0†	74.5			− 7.5
79.9	+ 9.87	+ 5.2	+ 1.5	75.0	+ 4.0	− 4.0	
80.0		+ 5.6†	+ 2.5	80.0	− 4.0	− 6.4	−11
83.4	+ 4.88		− 5.0	83.5	−11.0	−16.0	−17.1
86.4	+ 1.00	− 3.0	− 6.2	85	− 9.6		
87.3		− 2.3		86.8	−12.9		−16.8§
88.3		− 2.5	− 5.0	88.3	− 7.5	−13.8	−16.2
$\lambda$	590	740	930	$\lambda$	1240	1700	2130
$i$	39 Co			$i$	39 Co		
18.0		+1.3	+1.1	18.0		+ 0.2	0
18.6	+1.60			29.8	+ 0.8		
40.8	+3.98			41.8	+ 1.5	+ 1.2	+ 1.0
41.8		+4.0	+3.0	56.8	+ 1.8	+ 1.0	+ 0.8
56.8		+5.6	+4.7	66.9		+ 1.5	+ 0.3
66.9	+7.30			72.5	+ 1.6		
74.6	+6.56			75	+ 0.7	− 0.5	+ 1.6
75		+5.7	+4.3	77.5	− 0.9		
83.4	−1.00			80	− 3.9		
83.5		−1.7	−6.2	83.5		− 9.2	− 5.8
85			−8.6	85	−12.5	−13.4	
86.4	−2.07			86.5		−13.0	−14.5
86.5		−3.5	−7.8	88	− 8.9		

\*  $i$  is  $0.1^\circ <$  tabulated. †  $i$  is  $0.1^\circ >$  tabulated. ‡  $i$  is  $0.2^\circ >$  tabulated. §  $i$  is  $0.6^\circ >$  tabulated. ||  $i$  is  $0.3^\circ <$  tabulated.

$\lambda$	590	$\lambda$	740	1240	2120
$i$	49 Ni	$i$	49 Ni		
40.8	+1.24	20	−0.3	−0.7	−1.2
66.9	+0.70	60.5	−0.9	−3.6	−3.1
79.9	−1.41	67	−1.0	−5.4	−3.9
83.4	−2.09	74.8	−2.7	−5.9	−5.6



TABLE 6.—(Continued)

$\lambda$	590	$\lambda$	740	1240	2120
$i$	49 Ni	$i$	49 Ni		
86.4	-1.40	80	-4.5	-7.9	-6.3
		85	-3.9	-7.3	-5.8
		87.5	-2.3	-5.9	-4.1
		88.6	-1.3	-4.0	-2.3

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Barker, 67, 29: 1; 26. (2) Dziewulski, 63, 13: 642; 12. (3) Foote, 2, 34: 96; 12. (4) Ingersoll, 3, 11: 41; 06. (5) Ingersoll, 3, 18: 74; 09. (6) Ingersoll, 2, 35: 312; 12. (7) Kundt, 8, 23: 228; 84. (8) Loria, 8, 38: 889; 12. (9) Martin, 8, 39: 625; 12. (10) Martin, 8, 55: 561; 18. (11) Rigbi, 6, 9: 65; 86. (12) Rigbi, 6, 10: 200; 87. (13) Skinner and Tool, 3, 16: 833; 08.

## MAGNETOSTRICTION AND ALLIED EFFECTS

S. R. WILLIAMS

Magnetostriction comprises that group of magnetic phenomena in which the application of a magnetic field is accompanied by changes in dimensions of the body, and those reciprocal relations in which the application of a stress is accompanied by changes in magnetic properties. The names of the various phenomena, and the more important or interesting papers treating of them, are as follows:

## Length Effects

Joule effect—change in length due to a magnetic field (3, 4, 7, 8, 13, 20, 24, 27, 35, 36, 39, 46, 59, 62).

Villari effect—change in magnetization due to a longitudinal stress (15, 26, 32, 52, 54, 60).

Transverse Joule effect—change in dimensions normal to magnetic field (9, 20, 27, 59).

Transverse Villari effect—change in magnetic properties normal to stress.

Wertheim effect—bending due to a magnetic field (17, 34, 55).

Converse of Wertheim effect—magnetic properties changed by bending.

Change in Young's modulus due to a magnetic field (12, 25, 47, 48, 49).

## Circular Effects

Wiedemann effect—twist due to interaction of longitudinal and circular fields (6, 16, 29, 39, 43, 56, 58).

Wiedemann effect, No. 2—longitudinal magnetization produced by twisting circularly magnetized rod (39, 56).

Wiedemann effect, No. 3—circular magnetic field produced by twisting longitudinally magnetized rod (37, 39, 56).

Coefficient of rigidity changed by magnetization (12, 25, 47, 48, 49).

Mechanically twisted rods twisted by a circular or longitudinal magnetic field.

## Volume Effects

Barrett effect—volume change due to magnetization (4, 11, 30, 38).

Nagaoka and Honda effect—changes in magnetic properties due to hydrostatic pressure.

Change in bulk modulus due to a magnetic field (12, 25, 47, 48, 49).

## Allied Effects

Change in electrical resistance due to a magnetic field (19, 31, 40, 42, 57); see p. 414.

Change in thermoelectric emf's due to a magnetic field (1, 45, 50, 51); see p. 213.

Emf due to magnetization (10, 14, 41, 44).

Change in frequency of a tuning fork when subjected to a magnetic field (28, 33).

Sounds produced by magnetization (2, 3, 22, 53, 51, 63).

The Joule and the Villari are the fundamental magnetostrictive effects, the others being merely special cases of them or of the superposition of two or more of them. The changes in the elastic moduli are to be regarded as the result of the changes in dimension which result from the Joule effects.

Owing to the many factors which affect magnetostrictive phenomena—heat treatment, stress, hardness, impurities, previous magnetic history, etc., which factors are unknown in most of the work which has been done—it is extremely difficult to estimate the accuracy of the data. Those given in the following tables were selected as illustrative, rather than as exact numerical data applicable to definite materials; and the materials represented are those which will probably be most frequently needed for comparative studies. Much additional information will be found in the papers already listed.

In careful work, the Joule effect can be determined with an accuracy of 4% to 5% for iron, and with a somewhat lower accuracy (4% to 6%) for other materials; the Wiedemann effect can be observed to a higher precision; the Barrett effect is extremely difficult to measure; 10% is a fair average of probable error.

If at the center of a bar the magnetic field is  $H-NI$ , where  $H$  is the applied field and  $I$  is the intensity of magnetization of the bar,  $N$  is called the *demagnetizing factor*. Most data are expressed in terms of  $H-NI$ ; exceptions are suitably indicated.



TABLE 1.—LONGITUDINAL JOULE EFFECT

Tabular values =  $A$ ;  $A \times 10^{-6} = (l - l_0)/l_0$ ;  $l, l_0$  = length of specimen in field =  $H$ , field = 0. Unit of  $H$  = 1 cgs = 1 gauss; of one constituent (C, Ni, or Co) of alloy = 1%;  $t$  = centigrade temperature

Fe, C, Iron-carbon alloys (13)														Fe, Soft* iron (24)							
$\begin{matrix} C \\ H \end{matrix}$		0.60	0.74	0.89	0.98	1.18	1.37	$\begin{matrix} C \\ H \end{matrix}$		0.60	0.74	0.89	0.98	1.18	1.37	$\begin{matrix} t \\ H \end{matrix}$		-186	8.4	168	319
20		1.24	0.75	0.2	0.36	0.87	0.70	600		-4.88	-4.09	-3.82	-4.24	-3.68	-3.65	50		1.86	1.60	1.06	2.00
40		1.68	1.24	0.5	0.77	1.38	1.40	700		-5.52	-4.60	-4.34	-4.73	-4.25	-4.14	100		3.30	3.20	3.20	4.53
60		1.76	1.41	0.65	0.92	1.44	1.53	800		-5.86	-4.99	-4.67	-5.13	-4.65	-4.52	150		2.93	3.03	3.40	4.78
80		1.74	1.34	0.67	0.87	1.37	1.47	1000		-6.28	-5.53	-5.24	-5.72	-5.36	-5.13	200		2.10	2.40	3.10	4.74
100		1.56	1.17	0.57	0.72	1.22	1.26	1200		-6.65	-5.84	-5.62	-6.12	-5.86	-5.58	300		-0.30	0.55	1.75	4.21
200		0.10	-0.04	-0.34	-0.42	0.07	-0.06	1400		-6.96	-6.02	-5.90	-6.38	-6.21	-5.87	400		-2.56	-1.15	0.40	3.68
300		-1.46	-1.43	-1.46	-1.79	-1.20	-1.23	1600		-7.24	-6.09	-6.08	-6.56	-6.42	-6.01	500		-4.50	-2.63	-0.72	3.20
400		-2.88	-2.54	-2.38	-2.83	-2.24	-2.29	1800		-7.53	-6.15	-6.23	-6.74	-6.57	-6.16	600		-6.07	-3.90	-1.67	2.80
500		-4.03	-3.43	-3.20	-3.61	-3.04	-3.04									700		-7.25	-4.95	-2.22	2.50
																800		-8.20	-5.70	-2.63	2.30
																900		-9.14	-6.05	-3.00	2.18

\* Demagnetizing factor = 0.0683, not corrected for;  $H$  = applied field.

Fe, Ni, Iron-nickel alloys (21)											Ni, Nickel* (24)				
<div><div>H</div><div>Ni</div></div>	0	9.2	18.5	29.1	36.9	50	70	73.8	83	92.3	<div><div>H</div><div>t</div></div>	-186	17.2	197	376
50	2.63	2.14	1.86	2.54	12.10	12.20	7.23	3.00	-5.75	-10.75	50	-6.75	-9.60	-7.43	-0.19
100	2.82	4.17	3.72	3.68	15.93	16.40	9.10	3.30	-6.38	-17.30	100	-15.53	-20.00	-13.85	-0.49
150	2.28	5.83	5.56	4.29	17.30	18.00	9.82	3.43	-6.65	-20.10	150	-20.65	-26.00	-16.92	-0.53
200	1.64	7.18	7.02	4.79	18.13	18.95	10.26	3.53	-6.81	-22.05	200	-23.80	-29.70	-18.33	-0.55
250	0.96	8.32	8.17	5.26	18.67	19.58	10.61	3.63	-6.92	-23.20	300	-27.20	-33.10	-19.52	-0.55
300	0.35	9.33	9.15	5.72	19.10	19.96	10.90	3.72	-6.98	-23.57	400	-29.75	-34.70	-20.10	-0.54
350	-0.18	10.23	10.03	6.17	19.45	20.30	11.13	3.78	-7.00	-23.75	500	-32.00	-35.45	-20.50	-0.54
400	-0.63	11.02	10.80	6.63	19.80	20.63	11.29	3.83	-7.02	-23.92	600	-33.80	-36.03	-20.70	-0.54
450	-1.00	11.74	11.50	7.08	20.10	20.95	11.42	3.88	-7.04	-24.10	700	-35.27	-36.50	-20.90	-0.54
500	-1.31	12.41	12.12	7.53	20.35	21.26	11.52	3.91	-7.05	-24.27	800	-36.44	-36.82	-21.00	-0.54
550	-1.57	13.45	12.71	7.98	20.60	21.58	11.60	3.95	-7.05	-24.45	900	-37.30	-37.10	-21.02	-0.54

Fe, Co, Iron-cobalt alloys (21)											Cu, Mn, Al, Heusler alloys† (18)				
<div><div>Co</div><div>H</div></div>	0	10	20	30	40	50	70	80	90	100	H	I	II	III	IV
50	2.97	10.45	13.85	21.40	28.70	17.00	20.70	4.36	-5.40	-2.55	50	0.990	0.184	0.700	0.646
100	3.10	13.30	17.16	27.10	37.00	27.00	34.60	4.76	-6.58	-4.60	100	1.270	0.223	1.030	0.784
150	2.62	14.55	19.00	29.56	40.40	33.90	43.55	4.00	-6.65	-6.07	150	1.405	0.249	1.137	0.867
200	2.00	15.33	20.06	30.75	42.23	39.00	49.72	2.83	-6.50	-6.96	200	1.505	0.263	1.169	0.929
250	1.20	15.84	20.60	31.21	43.60	43.10	54.30	1.44	-6.22	-7.64	250	1.577	0.266	1.191	0.964
300	0.30	16.10	20.87	31.36	44.47	46.20	57.35	0.06	-5.87	-8.16	300	1.627	0.269	1.213	0.981
350	-0.46	16.20	20.95	31.44	44.99	48.50	59.67	-1.26	-5.52	-8.60	350	1.665	0.272	1.234	0.989
400	-1.07	16.16	20.92	31.49	45.37	50.25	61.40	-2.25	-5.13	-9.03	400	1.692	0.275	1.255	0.997
450	-1.56	16.06	20.82	31.49	45.62	51.62	62.78	-3.20	-4.70	-9.45	450	1.710	0.278	1.274	1.040
500	-1.98	15.91	20.69	31.49	45.80	52.80	63.83	-4.10	-4.25	-9.83	500	1.723	0.280	1.294	1.011
550	-2.32	15.78	20.58	31.50	46.00	53.85	64.67	-4.96	-3.78	-10.21	550	1.734	0.283	1.313	1.016

\* Demagnetizing factor = 0.0801, not corrected for;  $H$  = applied field.

† I = 64.49Cu, 20.39Mn, 13.25Al; II = 70.14Cu, 18.03Mn, 10.03Al; III = 59.43Cu, 22.60Mn, 14.50Al; IV = 65.22Cu, 19.76Mn, 11.13Al.

TABLE 2.—JOULE EFFECT: MAGNETITE CRYSTAL (20)

$A_2, A_3, A_4$  = value of  $A$  along the digonal, trigonal, tetragonal axis.  $A \times 10^{-6} = (l - l_0)/l_0$ ;  $l, l_0$  = length in field =  $H$ , in field = 0. Unit of  $H$  = 1 cgs = 1 gauss.

$H$	Longitudinal			Transverse		
	$A_2$	$A_3$	$A_4$	$A_2$	$A_3$	$A_4$
900	4.04	2.01	-0.54	-7.60	-2.60	0.76
1000	5.10	2.42	-0.63	-9.75	-3.50	0.91
1500	10.09	4.46	-1.18	-18.50	-8.10	1.67
2000	14.35	6.37	-1.82	-25.25	-12.40	2.42
2500	17.85	8.04	-2.47	-30.55	-16.33	3.07
3000	20.93	9.40	-3.03	-35.10	-19.60	3.57
3500	23.80	10.48	-3.50	-38.70	-22.13	3.94
4000	26.57	11.34	-3.85	-41.33	-24.04	4.20
4500	29.20	12.04	-4.08	-43.20	-25.77	4.35

TABLE 3.—CHANGE IN YOUNG'S MODULUS WITH MAGNETIC FIELD

$E, E_0$  = Young's modulus in field =  $H$ , field = 0;  $F$  = tension of specimen;  $\Delta F$  = increase of  $F$  in determination of  $E$ ;  $(E - E_0)/E_0 = 0.01A$ . Tabular values =  $A$ . Unit of  $F$  = 1 kg/cm<sup>2</sup> = 980 665 barye = 14.22 lb./in.<sup>2</sup>

Ni, Nickel (25); 10.0°C, $\Delta F = 74.3$										Fe*	
$H \backslash F$		154.0	302.1	449.8	$H \backslash F$		154.0	302.1	449.8	$H \backslash F$	
5		-0.13	-0.30	-0.10	80		-2.32	-8.18	-7.92	50	0.08
10		-1.40	-0.70	-0.23	90		-1.62	-6.35	-9.86	75	0.15
20		-5.80	-1.73	-0.67	100		-1.08	-5.00	-9.80	100	0.18
30		-11.30	-3.18	-1.31	150		+0.24	-1.78	-4.44	150	0.22
40		-13.00	-5.27	-2.17	200		+1.03	-1.15	-3.03	200	0.24
50		-7.30	-8.55	-3.23	300		+2.14	-0.37	-1.47	300	0.26
60		-4.60	-11.85	-4.55	400		+2.40	+0.22	-0.78	400	0.28
70		-3.26	-11.54	-6.10							

\* Swedish iron (25); 11.5°C,  $\Delta F = 78.4$ .



TABLE 4.—WIEDEMANN EFFECT ( $\varphi$ )

The circular field is in all cases produced by the current  $J$  flowing along the geometrical axis of the specimen, which is a circular cylinder, bar or tube.  $H$  = longitudinal field which produces the twist  $\varphi$ . Looking in direction of  $H$ , the positive direction of  $\varphi$  is that of the circular field produced by  $J$ . Tabular values =  $\varphi$ . Unit of  $H$  = 1 cgs = 1 gauss;  $J$  = 0.1 cgs = 1 ampere;  $\varphi$  = 1" per cm of length.

Fe, Iron bar (23)				Ni, Nickel bar (23)			
$H \backslash J$	3.12	5.26	8.86	$H \backslash J$	2.00	4.37	6.55
25	0.057	0.080	0.186	25	-0.288	-0.888	-1.243
50	0.235	0.408	0.706	50	-0.302	-1.052	-1.421
75	0.435	0.648	0.954	75	-0.217	-0.879	-1.221
100	0.466	0.688	0.941	100	-0.164	-0.733	-1.021
150	0.364	0.515	0.733	150	-0.089	-0.506	-0.755
200	0.280	0.377	0.533	200	-0.058	-0.371	-0.577
300	0.155	0.222	0.302	300	-0.026	-0.222	-0.386
400	0.106	0.151	0.186	400	-0.022	-0.164	-0.293
500	0.071	0.071	0.120	500	-0.018	-0.133	-0.244
600	0.044	0.062	0.084	600	-0.016	-0.106	-0.200
700	0.022	0.044	0.062	700	-0.013	-0.075	-0.146

Fe, C, Low carbon steel: tubes (58)

$H \backslash J$	0.52	1.00	1.50	1.50	2.00
10	0.301	0.702	1.253	0.251	0.377
20	1.332	2.682	4.436	1.255	1.757
30	1.805	3.561	5.226	1.962	2.610
40	1.499	2.924	4.493	1.862	2.534
50	1.223	2.387	3.684	1.606	2.133
60	0.978	1.959	2.964	1.330	1.752
70	0.771	1.583	2.362	1.104	1.418
80	0.616	1.285	1.917	0.916	1.129
90	0.499	1.063	1.575	0.763	0.898
100	0.405	0.877	1.296	0.627	0.713
150	0.065	0.277	0.382	0.070	0.109
200	-0.095	-0.018	+0.012	-0.100	-0.031
250	-0.160	-0.150	-0.217	-0.109	-0.105
$d_o^* = 0.1600$ cm			0.2447 cm		
$d_i^* = 0.0794$ cm			0.0970 cm		
$l^* = 79.8$ cm			79.7 cm		

\*  $d_o$ ,  $d_i$  = outer, inner diameter of tube,  $l$  = free length of tube.

TABLE 5.—NAGAOKA-HONDA EFFECT (12)

$B$ ,  $B_0$  = Magnetic induction in specimen in field  $H$  when pressure =  $P$ , pressure = 0;  $A = (B - B_0)/BP$ . Unit of  $A$  =  $10^{-6}$  cm<sup>2</sup>/kg =  $1.0197 \times 10^{-11}$  barye<sup>-1</sup> =  $7.0307 \times 10^{-7}$  in.<sup>2</sup>/lb. =  $1.0332 \times 10^{-6}$  A<sub>n</sub><sup>-1</sup>; of  $H$  = 1 cgs = 1 gauss; of  $P$  = 1 kg/cm<sup>2</sup> = 980 665 barye = 14.22 lb./in.<sup>2</sup> =  $0.9678 A_n$ .

Fe, C, Iron; * $H = 1.30$				Fe, Iron; † $P = 7.510$			
$P$	$A$	$P$	$A$	$H$	$A$	$H$	$A$
1 010	-2.13	7 590	-1.90	0.27	-2.27	1.35	-5.38
1 930	-2.10	8 490	-1.95	0.38	-3.31	1.62	-4.72
3 470	-2.01	9 570	-1.94	0.54	-3.67	1.89	-3.86
4 370	-1.91	10 320	-1.95	0.76	-4.45	2.16	-3.14
5 360	-1.94	11 290	-1.94	0.97	-5.15	2.70	-2.27
6 460	-1.94			1.08	-5.51	3.79†	-1.43

\* Carbonized.

† Pure iron.

‡ For  $H = 4.87$ ,  $A = -0.99$ .

TABLE 6.—DEMAGNETIZATION OF RODS BY IMPACT AND BY TORSION

$\phi[\phi']$  = total magnetic flux across given section of rod before [after] impact or torsion;  $x$  = distance of section from end struck, or from clamped end;  $\theta$  = twist per unit length;  $D = (\phi - \phi')/\phi$ . Unit of  $\phi$  = 1 cgs = 1 maxwell;  $x$  = 1 cm;  $\theta$  = 1' per cm;  $D$  = 1 %.

Tool steel (5); single impact at  $x = 0$ ; total length = 110 cm

$x$	$\phi$	$D$	$x$	$\phi$	$D$	$x$	$\phi$	$D$
2	1296	11.0	29	7266	12.4	89	6301	10.6
5	2572	12.9	35	7831	12.0	95	5282	10.5
8	3349	14.2	44	8355	11.6	98	4666	10.5
11	4159	14.1	56	8559	11.5	101	3960	10.4
14	4864	13.9	68	8260	11.3	104	3122	10.2
17	5484	13.6	77	7675	10.9	107	2189	9.6
23	6497	13.0	83	7082	10.7	110	1089	8.2

Norway iron (5); uniform torsion; total length 110 cm. For  $30 < x < 80$ ,  $D$  is independent of  $x$ , and =  $D_c$ ; for points nearer the ends,  $D$  may differ from  $D_c$  by 12 % of  $D_c$ . Value of  $\phi$  at central section = 1500 maxwell.

$\theta$ .....	0.818	1.96	2.84	4.42	6.16
$D_c$ .....	21.6	43.2	55.7	68.2	77.6

## LITERATURE

(For a key to the periodicals see end of volume)

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## ATMOSPHERIC ELECTRICITY

W. F. G. SWANN

## CONTENTS

Potential gradient.	Gradient de potentiel.
Ionic content of atmosphere.	Teneur ionique de l'atmosphère.
Conductivity of atmosphere.	Conductibilité de l'atmosphère.
Miscellaneous data.	Données diverses.
Air-earth current density.	Densité de courant air-terre.
Rate of recombination of atmospheric ions.	Velocité de recombinaison des ions atmosphériques.
Charge on rain.	Charge sur la pluie.
Lightning.	Éclair.

## MATIERES

## INHALTSVERZEICHNIS

## INDICE

Potential-Gradient.	Gradiente di potenziale....	442
Ionengehalt der Atmosphäre.	Contenuto ionico dell'atmosfera.....	442
Leitfähigkeit der Atmosphäre.	Conducibilità dell'atmosfera.....	444
Verschiedene Daten.	Dati diversi.	
Stromdichte Luft-Erde.	Densità della corrente aria-terra.....	444
Geschwindigkeit der Wiedervereinigung atmosphärischer Ionen.	Velocità di ricombinazione dei ioni atmosferici.....	444
Ladung am Regen.	Carica della pioggia.....	444
Blitz.	Lampi.....	445

**Potential Gradient.**—See Tables 1, 2 and Figs. 1, 2, 3, 4. The values are supposed to represent the gradient as it would be if the effective surface of the earth were a true plane. The main sources of error lie in (a) an uncertainty of the correction for the non-planar form of the effective surface of the earth, and (b) errors due to leakage from the collector system (4). No precise limits of accuracy can be given without a precise study of each individual case, which is impracticable. As a result of the first (a) source of error, determinations on land have occasionally been unexpectedly found in error by as much as 50%. The importance of the second (b) source of error depends upon the speed of the collector; in a typical case in which it required one minute to obtain a reading within 1% of its final value, the error due to leakage resulting from atmospheric conductivity alone amounted to 1%.

From an analysis of the diurnal variation over the ocean, Mauchly (22) has concluded that this variation is primarily due to a 24 hour wave which progresses according to universal, rather than local, time; he finds the same 24 hour wave from land observations, but for these it is not so large a part of the entire effect.

TABLE 1.—POTENTIAL GRADIENT: LAND VALUES

For ocean values, see Table 2. Mean values over the interval indicated: Long. = longitude east of Greenwich, Pot. Grad. = potential gradient, potential increasing upwards. (See also Figs. 1 to 4.) Unit of Pot. Grad. = 1 volt/meter =  $3.336 \times 10^{-5}$  cgse unit per cm.

Place	Lat.	Long.	Interval	Pot. Grad.	Lit.
Karasjok.....	69.3° N.	25.6°	1 yr	139	(6)
Upsala.....	59.9 N.	15.2	2	70	(24)
Moscow.....	55.7 N.	37.6		112	(18)
Potsdam.....	52.4 N.	13.1	4	245	(6)
Kew.....	51.5 N.	359.7	15	304	(6)
Seeham.....	48.0 N.	13.1	12	84	(29)
Kremsmünster.....	48.0 N.	14.1	10	107	(6)
Munich.....	48.1 N.	11.6	5	168	(6)
Davos.....	46.8 N.	9.8	2	64	(6)
Trieste.....	45.6 N.	13.8	2	73	(6)
Perpignan.....	42.7 N.	357.1	2	55	(30)
Tortosa.....	40.8 N.	0.5	7	114	(6)
Buenos Aires.....	34.6 S.	301.6	1	126	(3)
Petermann I.....	65.2 S.	295.8	1	176	(14)

TABLE 2.—POTENTIAL GRADIENT, IONIC CONTENT AND CONDUCTIVITY OF THE ATMOSPHERE, AND AIR-EARTH CURRENT DENSITY: OCEAN VALUES

For land values, see Table 1, potential gradient; Table 3, ionic content; Table 4, conductivity and current density. Com-

puted from (4, 4.1); data are averages for the region, and are based on observations distributed over one or two weeks and taken near 10 A. M. local mean time. Long. = longitude east of Greenwich; Pot. Grad. = potential gradient, potential increasing upwards;  $n_+$  [ $n_-$ ] = number of + [−] ions per  $\text{cm}^3$  of air;  $\lambda_+$  [ $\lambda_-$ ] = conductivity due to + [−] ions;  $i$  = current density of positive current from air to earth,  $i = (\lambda_+ + \lambda_-) \times$  potential gradient. Dates are written thus: 3:20:15 = March 20, 1915. Unit of Pot. Grad. = 1 volt/meter =  $3.336 \times 10^{-5}$  cgse unit (per cm); of  $\lambda_+$  and  $\lambda_-$  =  $10^{-4}$  cgse unit; of  $i$  =  $10^{-7}$  cgse unit (per  $\text{cm}^2$ ).

Region		Mean date	Pot. Grad.*	$\frac{n_+ + n_-}{2}$	$\frac{n_+}{n_-}$	$\lambda_+ + \lambda_-$	$\frac{\lambda_+}{\lambda_-}$	$i$
Lat.	Long.							
°N.	°E.							
12-31	283-293	12:18:15	117	490	1.03	1.70	1.18	5.8
2-8	260-280	4:21:15	126	760	1.20	2.75	1.18	11.1
8-16	233-258	5: 5:15	115	860	1.05	2.90	1.24	10.4
17-21	204-230	5:16:15	109	920	0.93	3.28	1.05	12.1
22-36	199-201	4: 7:15	112	690	1.16	2.57	1.45	9.3
37-52	190-196	4:15:15	129	730	1.27	2.54	1.13	10.4
56-59	175-193	8:11:15	155	790	1.26	2.62	1.15	12.4
32-54	163-173	8:24:15	144	610	1.41	2.35	1.33	10.9
14-30	165-171	9: 8:15	115	880	1.16	3.19	1.22	12.0
2-14	162-166	9:23:15	102	820	1.19	3.18	1.18	10.7
1-19	158-163	10: 8:15	115	670	1.19	2.66	1.13	10.3
22-47	155-173	10:24:15	104	850	1.19	2.76	1.14	9.5
°S.	°E.							
46-56	175-198	12:11:15	109	840	1.28	2.63	1.25	10.0
59-60	209-271	12:24:15	145	660	1.30	2.50	1.34	11.7
54-59	280-327	1: 8:16	165	690	1.25	2.54	1.25	12.2
52-54	349-42†	1:26:16	114	630	1.15	2.10	1.23	7.9
36-52	47-93	2: 8:16	110	810	1.15	2.71	1.22	9.8
34-54	95-108	2:22:16	118	750	1.18	2.89	1.19	10.9
41-59	110-133	3: 8:16	138	820	1.26	3.02	1.25	14.2
45-57	135-173	3:26:16	122	870	1.18	2.83	1.14	14.1

\* Deduced from observed change in potential of a conductor that is moved in the earth's field (4).

† Taken, of course, over the lesser portion of the small circle.

**Ionic Content.**—The numbers  $n_+$  and  $n_-$ , of positive and of negative ions per  $\text{cm}^3$ , are derived from  $(n_+ + n_-)/2$  and  $n_+/n_-$  (Table 3). As the atmospheric potential gradient tends to decrease the rate at which negative ions enter the measuring instrument, the values of  $n_-$  are apt to be too low. The size of this error depends upon instrumental details and the effect of surrounding objects, and may exceed 20% (21, 23, 37, 38, 39). With the Ebert aspiration apparatus, the ions measured are mostly the so-called "small" ions, which, in laboratory experiments, have mobilities of 1.3 cm/sec per volt/cm for the +ions and 1.8



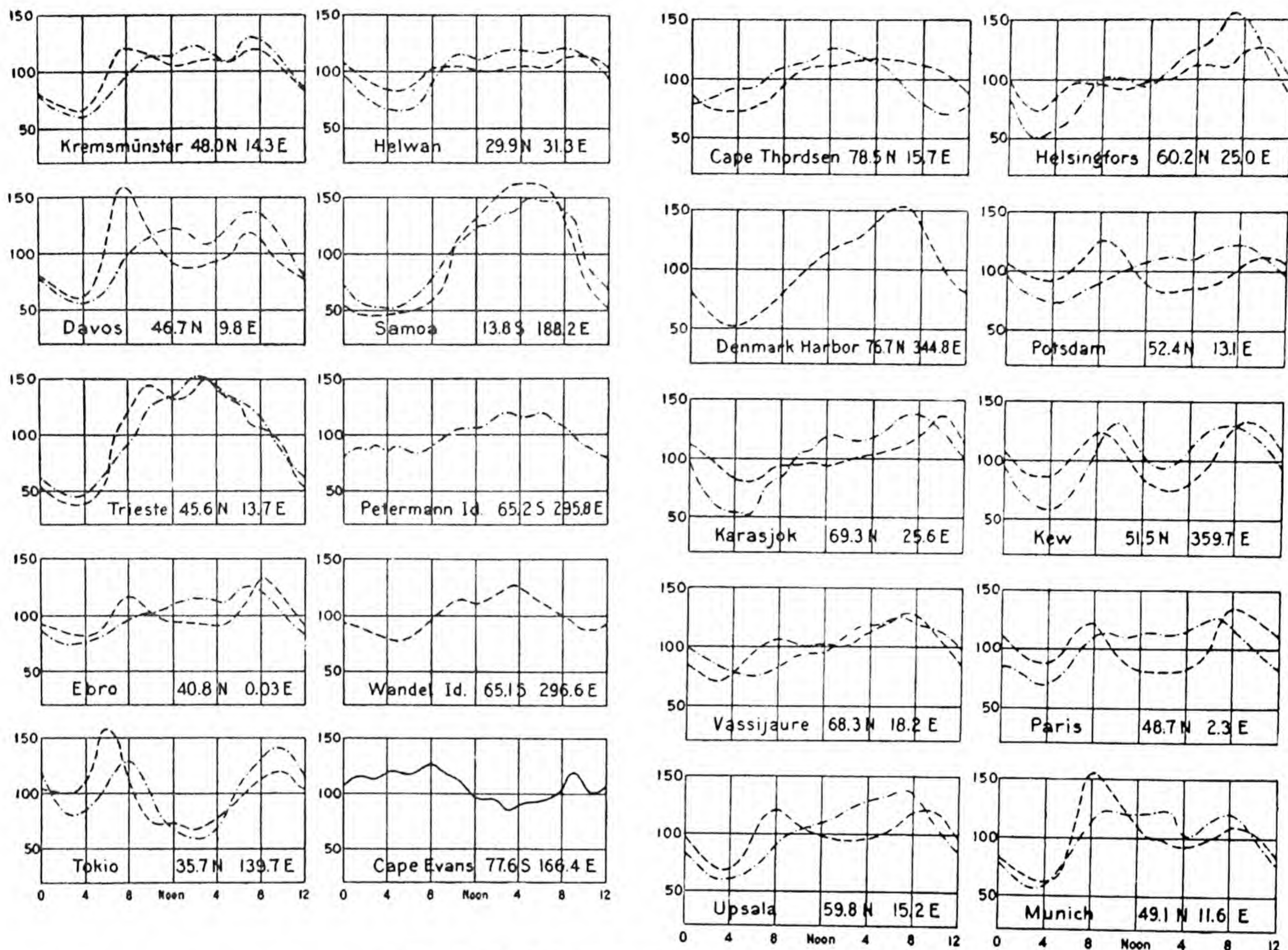


FIG. 1.—Diurnal variation of potential gradient (24).

Ordinates = percentage of the mean gradient for the season (summer, winter, or year), abscissae = local mean time. Summer — —, winter . ., year —.

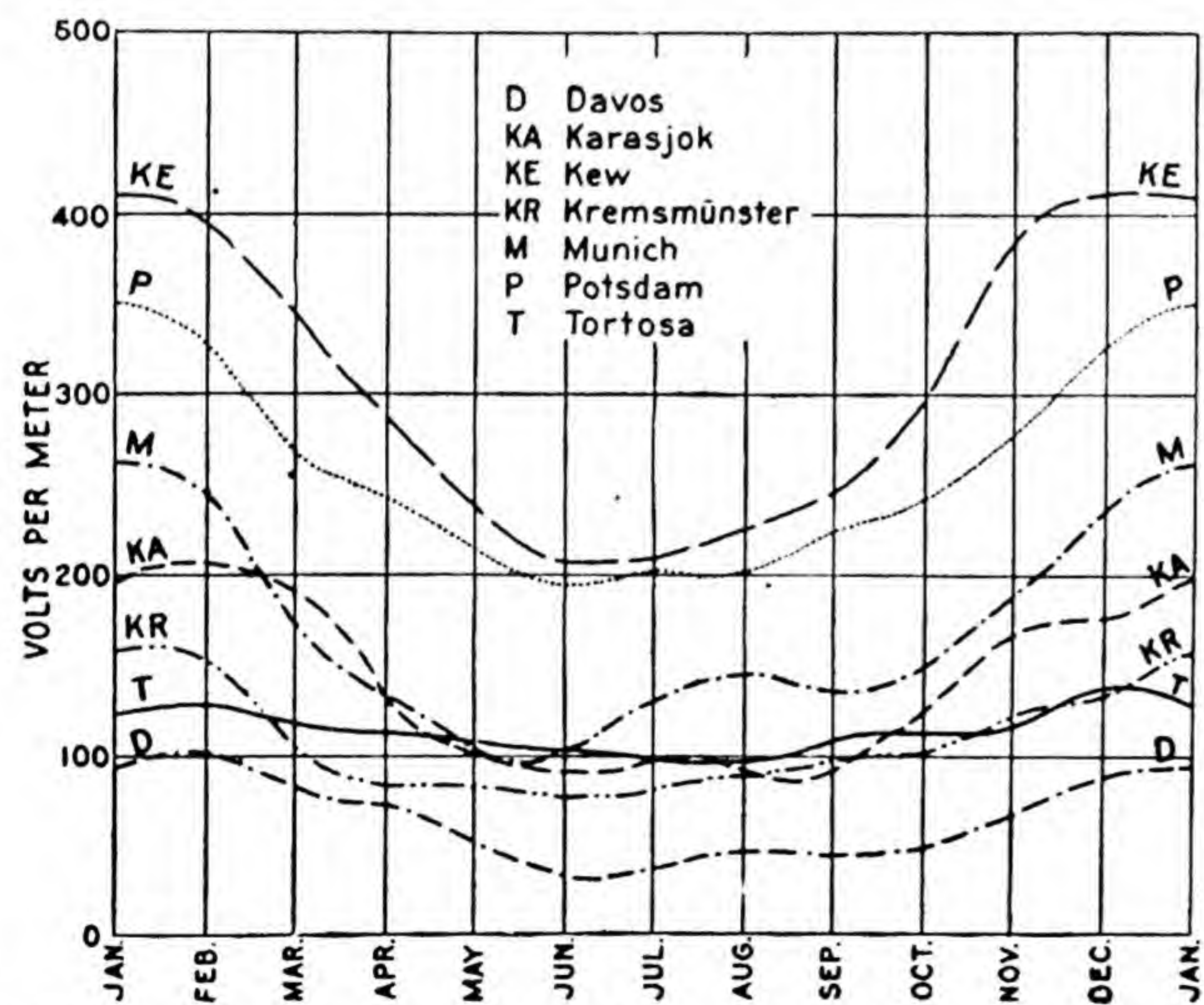


FIG. 2.—Annual variation of potential gradient: Northern hemisphere (°).

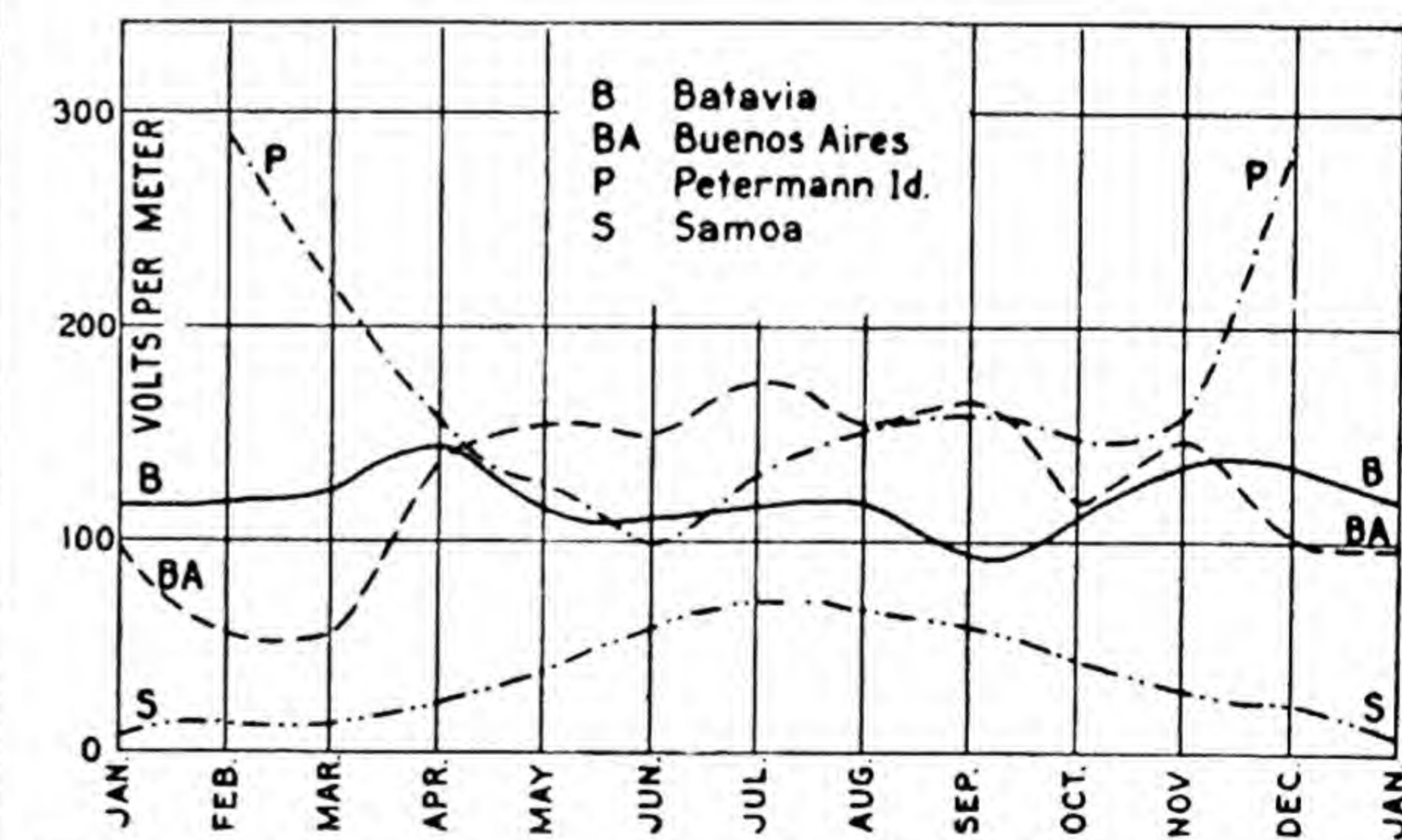


FIG. 3.—Annual variation of potential gradient: Southern hemisphere (°).



for the  $-$ ions. In addition to these, so-called "large" ions of mobility about 1/3000 cm/sec per volt/cm, and "intermediate" ions of mobility of the order 0.01 are to be found in the atmosphere. The numbers of these larger ions vary very widely. Representative ratios of large to small ions are: In Paris 50 (Langevin), in Swiss Alps and in Freiburg 2 to 3 (Gockel), in Dublin 200 (McClelland and Kennedy).

As determined on the fourth cruise of the Carnegie, the mobilities of the small ions over the Pacific and the sub-Antarctic Oceans averaged 1.3 cm/sec per volt/sec for both  $+$  and  $-$  ions. The large abnormalities in the mobilities of atmospheric "small" ions reported by some observers are probably attributable largely to experimental errors inherent in the methods used, the customary method with the Ebert apparatus leading in a large percentage of cases of observatory data to even a negative value of the mobility.

TABLE 3.—IONIC CONTENT OF ATMOSPHERE: LAND VALUES

For ocean values, see Table 2. These values have been reduced on the assumption that  $e = 4.8 \times 10^{-10}$  es unit; most of them were obtained with Ebert's aspiration apparatus (18, 36). Values of  $n_+/n_-$  are apt to be too high, and of  $n_-$  too low. Dates are written thus: 8: 19, 20; 05 = August 19, 20, 1905. Long. = longitude east of Greenwich. Unit of  $n_+$  and  $n_- = 1$  ion per cm.<sup>3</sup>

Place	Lat.	Long.	Period	$\frac{n_+ + n_-}{2}$	$\frac{n_+}{n_-}$	Lit.
Karasjok.....	69.3° N.	25.6	1 yr	750	1.17	(31)
Kew.....	51.5 N.	359.7	11 to 14	330	1.40	(45)
Freiburg.....	50.9 N.	16.3	04 to 05	624	1.36	(12)
Munich.....	48.1 N.	11.6	8: 19, 20; 05	994	1.24	(10)
Aibling.....	47.9 N.	12.0	06, summer	950	1.25	(8)
Aibling.....	47.9 N.	12.0	06, winter	913	1.19	(8)
Jachenau.....	47.6 N.	11.4	8: 05	915	2.16	(10)
Barcelona*.....	41.4 N.	2.2	1 day	541	1.30	(10)
Seewalchen.....	N.		8: 6 to 9: 20; 04	862	1.18	(27)
Bolivia†.....	S.		5: to 9: 09	1980	1.08	(19)
Buenos Aires.....	34.6 S.	301.6	5: 11 to 4: 12	1980	1.04	(3)

\* Barcelona harbor.

† In high Cordilleras.

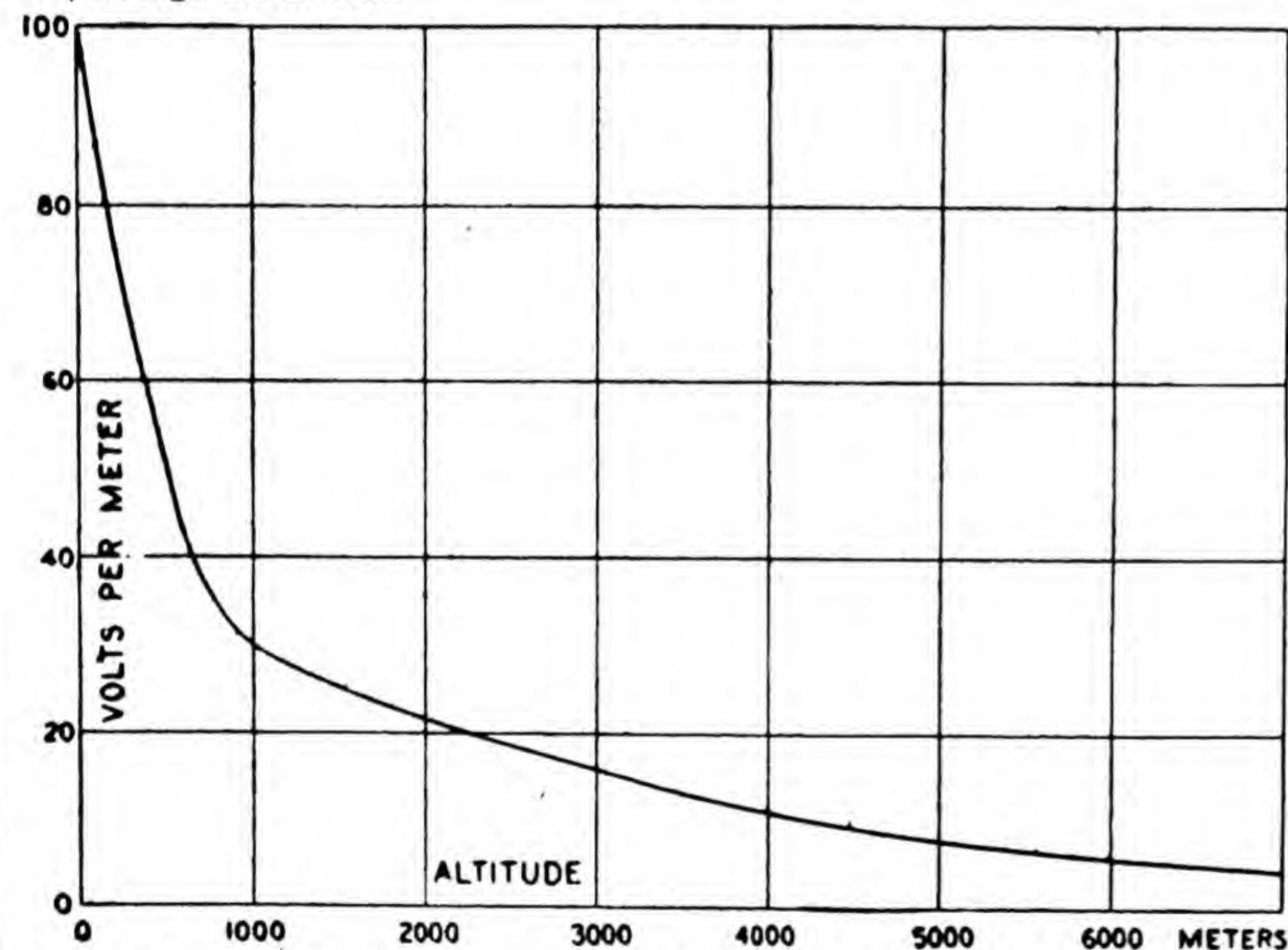


FIG. 4.—Variation of potential gradient with altitude (30).

Mean of results of various observers, each set reduced to correspond to 25 volt per meter at an altitude of 1500 meter.

**Conductivity of Atmosphere.**—(Tables 2 and 4.) The conductivity ( $\lambda_+ + \lambda_-$ ) of the atmosphere is the sum of the conductivities due to the presence of the  $+$  and of the  $-$  ions. For methods, see (18). Values of ( $\lambda_+ + \lambda_-$ ) obtained by the Gerdien apparatus are apt to be too low, owing to neglect of effect of rod supporting the central cylinder. This error may amount to 10% or 15% (35). In the ocean data recorded in Table 2, the measurements were taken in such a manner as to avoid this error. For

land observations, the measured value of  $\lambda_+$  is apt to be too high on account of the collection on the apparatus of radioactive material from the atmosphere. This error may amount to 5%.

Values obtained by Schering's method, which involves measurement of rate of flow of charge from a body (usually a long wire) exposed to the free air, are apt to be too low on account of effect of earth's electric field (34), unless that field near the apparatus is very small, as seems to be the case at Potsdam. When this effect is neglected the values obtained are 20% to 30% lower than those obtained with the Gerdien apparatus.

TABLE 4.—CONDUCTIVITY OF ATMOSPHERE, AND AIR-EARTH CURRENT DENSITY: LAND VALUES

For ocean values, see Table 2; for values at high altitude, see Table 5. Long. = longitude east of Greenwich;  $\lambda_+$ ,  $\lambda_-$  = conductivity due to  $+$ ions,  $-$ ions;  $i$  = current density of positive current from air to earth,  $i = (\lambda_+ + \lambda_-) \times$  potential gradient. Dates are written thus: 5: 09–4: 10 = May, 1909 to April, 1910; 4: 1–17; 06 = April 1 to 17, 1906. Unit of  $\lambda_+$  and  $\lambda_- = 10^{-4}$  cgse unit; of  $i = 10^{-7}$  cgse unit.

Place	Lat.	Long.	Period	$\lambda_+ + \lambda_-$	$\lambda_+/\lambda_-$	$i$	Lit.
Greenland*.....	73.0° N.		07 to 08	5.53	1.28	12.6	(6)†
Edinburgh†.....	56.0 N.	356.9	5–6: 09	0.72		8.4	(5)
Peebles†.....	55.7 N.	356.8	9: 06–10: 07	2.16		13.4	(42)
Potsdam§.....	52.4 N.	13.1	5: 09–4: 10	0.95	1.16	7.1	(17)
Göttingen*.....	51.5 N.	9.9	4: 1–17; 06	2.22	0.98	8	(11)
Munich†.....	48.1 N.	11.6	1–12: 09	0.98		6.1	(46)
Seeham§.....	48.0 N.	346.9	08–20	2.64	1.02	6.9	(29)
Davos§.....	46.8 N.	9.8	1 year	2.68	1.13	5.2	(9)
Simla†.....	31.2 N.	77.8	11: 09	11.6		10.8	(32)
Samoa*.....	13.8 S.	188.2	6: 07–3: 08	4.5	1.04	7.0	(1)
Buenos Aires*.....	34.6 S.	301.6	4, 6: 12	1.32	1.02	5.7	(3)
Petermann I*.....	65.2 S.	295.8	9 months	4.16	1.62	22.6	(6)†

\* By Gerdien's conductivity apparatus; values may be too low by 10% or 15%, see text.

† By C. T. R. Wilson's method. Values of ( $\lambda_+ + \lambda_-$ ) =  $2\lambda_0$ ,  $\lambda_0$  = directly observed  $\lambda$ ;  $i = 2\lambda_0 \times$  potential gradient.

‡ Vol. III, p. 123 (6); observed by Wegener.

§ By Schering's method; values may be too low, see text.

TABLE 5.—CONDUCTIVITY OF ATMOSPHERE AT HIGH ALTITUDES (41)

Results of 4 ascensions; in each, data are reduced to correspond with ( $\lambda_+ + \lambda_-$ ) = (1 to 1.5)  $\times 10^{-4}$  cgse unit at earth's surface. Altitude = maximum altitude, tabulated values of ( $\lambda_+ + \lambda_-$ ) correspond to that altitude.

Ascension	1	2	3	4	Unit
( $\lambda_+ + \lambda_-$ ).....	16.5	18.8	23.2	37.3	$10^{-4}$ cgse
Altitude.....	5300	5385	8345	8865	meter

**Miscellaneous Data.**—The air-earth current density is computed from the potential gradient and the conductivity, and is usually expressed in cgs electrostatic units per cm<sup>2</sup> (=cgse units). See Tables 2 and 4.

**Rate of Recombination of Atmospheric Ions.**—As determined by laboratory experiments with artificial ionization, the coefficient  $\alpha$  in  $\frac{dn_{\pm}}{dt} = \alpha n_+ n_-$  has a value about  $1.6 \times 10^{-6}$  cm<sup>3</sup> per (ion sec) (cf. p. 110), but for atmospheric ions,  $\alpha$  has, in general, been found to be of the order of (2 or 3)  $\times 10^{-6}$ . Recent work (25, 28) indicates that for atmospheric ions  $\frac{dn_{\pm}}{dt} = \alpha n_+ n_- + \beta n_{\pm}$ , where  $\beta$  is considerably more important than  $\alpha$ .

**Charge on Rain.**—Rain may be charged either  $+$  or  $-$ . In Simla, Simpson (32) found that  $+$  precipitation occurred 2.5 times as frequently as  $-$  precipitation, and in a long series of observations the total  $+$  charge brought down was 3.2 times as great as the total  $-$  charge. The corresponding values found at Potsdam (26) by Schindelbauer (confirmed by Kähler) are 2.2 and 1.4, and at Le-Puy-en-Velay by Baldit (2) are 2.86 and 1.36,



respectively. The charge on rain is generally less than 1 es unit per cm.<sup>3</sup>

**Lightning.**—Humphreys (16) estimates that the current associated with a lightning flash may, in certain cases, be of the order of 90 000 amperes. From a comprehensive series of experiments, C. T. R. Wilson (43) concludes that the average charge brought down in a lightning flash is of the order of 20 coulombs, and that the potential differences involved in the discharge are of the order of  $10^9$  volt.

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(For a key to the periodicals see end of volume)

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## TERRESTRIAL MAGNETISM

W. F. G. SWANN

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Terrestrial magnetism.	Magnétisme terrestre.	Erdmagnetismus.	Magnetismo terrestre.	
General conclusions.	Conclusions générales.	Allgemeine Schlüsse.	Conclusioni generali . . .	445
Magnetic elements at various observatories: recent data.	Éléments magnétiques à des observatoires différents: données récentes.	Magnetische Elemente verschiedener Observatorien: neue Daten.	Elementi magnetici nei vari osservatori: dati recenti . . . . .	446
Magnetic elements for each 10° of latitude and longitude between 70° N. and 60° S. latitude.	Éléments magnétiques pour chaque 10° de latitude et longitude entre 70° N. et 60° S. de latitude.	Magnetische Elemente für je 10° der Länge und Breite zwischen 70° N. und 60° S. Breite.	Elementi magnetici per ogni 10° di latitudine e longitudine fra 70° N. e 60° S. di latitudine . .	446
Curves of equal declination, of equal inclination, of equal horizontal intensity: for 1922.	Courbes d'égale déclinaison, d'égale inclinaison, d'égale intensité horizontale: pour 1922.	Kurven gleicher Deklination, gleicher Inklination und gleicher horizontaler Intensität für das Jahr 1922.	Curve per il 1922 di declinazione uguale, di inclinazione uguale e di intensità orizzontale uguale . . . . .	448
Diurnal variations at selected stations.	Variation diurne à des stations choisies.	Tägliche Änderung an ausgewählten Stationen.	Variatione diurna in alcune stazioni . . . . .	449
Secular changes in declination at various places and over long periods (150 yr to 380 yr).	Changements séculaires de la déclinaison à des places diverses et pour de longues périodes (150 ans à 380 ans).	Säkulare Änderung der Deklination an verschiedenen Orten und für eine lange Periode (150 bis 380 Jahre).	Cambiamenti secolari della declinazione nei vari posti e in lunghi periodi di tempo (150 anni a 380 anni) . . . . .	449
Secular changes in magnetic elements at various observatories: 1905 to 1925.	Changements séculaires des éléments magnétiques à divers observatoires: 1905 à 1925.	Säkulare Änderung magnetischer Elemente an verschiedenen Observatorien: 1905 bis 1925.	Cambiamenti secolari negli elementi magnetici ai vari osservatori dal 1905 al 1925 . . . . .	449
Earth currents.	Courants terrestres.	Erdströme.	Correnti terrestri . . . . .	449
Aurora.	Aurore.	Aurora.	Aurora . . . . .	449

**General Conclusions.**—The magnetic field of the earth is roughly that of a uniformly magnetized sphere; at external points the field of such a sphere is equivalent to that due to a magnetic doublet placed at the center of the sphere. The axis of the doublet is inclined to the axis of rotation. If  $M$  is its moment, and  $M_p$  and  $M_e$  are, respectively, the axial and the equatorial components of  $M$ , then, according to an analysis by L. A. Bauer (4),  $M = 8.04(10)^{25}$ ,  $M_p = 7.88(10)^{25}$ ,  $M_e = 1.60(10)^{25}$  cgs magnetic unit; the axis of the doublet intercepts the northern hemisphere at latitude  $78^\circ 32'$  N. and longitude  $69^\circ 08'$  W.; and the average intensity of magnetization of the earth is 0.074 cgs magnetic unit.

The magnetic poles, defined as the places where the field is vertical, are not where the prolonged axis of the doublet intersects

the earth's surface. From observations between 1903 and 1906, Amundsen placed the north magnetic pole at lat.  $71^\circ$  N, long.  $96^\circ$  W.; from data obtained on the "Discovery," 1902 to 1904, the probable position of the south magnetic pole is latitude  $72^\circ 50'$  S., longitude  $156^\circ 20'$  E.

From a harmonic analysis of the field, Gauss concluded that part of it is of external origin. Analyses by Schmidt (13) and by Bauer (4) lead these authors to conclude that a part of the field is not derivable from a potential; Bauer (4) concludes that about 3% of the field is of non-potential origin, and, of the remainder, 94% arises from internal, and 3% from external, causes. The non-potential portion would correspond, on classical electromagnetic theory, to vertical currents (see Table 1).



TABLE 1.—VERTICAL CURRENT DENSITIES AS COMPUTED FROM  
MAGNETIC DATA

Computed by Bauer (3) from magnetic data of 1920. The average value, regardless of sign, is about 10 000 times the atmospheric-electric current density, see p. 442. Dyson and Furner (8) conclude that such vertical currents are not indicated with any certainty, although there is some evidence for them. A + sign indicates an upward positive current;  $i_N$  [ $i_S$ ] = current density in northern [southern] hemisphere. Unit of  $i_N$  and  $i_S$  =  $10^{-3}$  ampere/km<sup>2</sup> =  $3.0 \times 10^{-4}$  cgse (per cm<sup>2</sup>).

Lat.	$i_N$	$i_S$
90° to 50°	+21	+18
50 to 45	+45	+34
45 to 40	- 6	-47
40 to 35	+18	-22
35 to 30	+ 8	-31
30 to 25	-29	+19
25 to 20	-37	+58
20 to 15	-19	+41
15 to 10	-33	-41
10 to 5	-53	+14
5 to 0	-18	+ 9

TABLE 2.—MAGNETIC ELEMENTS AT VARIOUS OBSERVATORIES:  
RECENT DATA (9)

$D$  = declination (east or west);  $I$  = inclination or dip (north or south);  $H$  = horizontal intensity,  $Z$  = vertical intensity. *Italics* indicate that the quantity is to the south (latitude and  $I$ ) or the west (longitude and  $D$ ); in column "Yr," 24 indicates 1924; Long. = longitude east or west from Greenwich. Unit of  $H$  and  $Z$  =  $1\gamma = 10^{-5}$  gauss =  $10^{-6}$  cgsm.

Observatory	Lat.	Long.	Yr	$D$	$I$	$H$	$Z$
Matohkin Shar.....	73° 15'	56° 24'	24	20° 35'	80° 03'	9 520	54 270
Sodankylä.....	67 22	26 39	22	1 22.6	75 40.5	12 561	49 187
Pavlovsk.....	59 41	30 29	24	3 16.1	71 07.9	15 818	46 970
Sitka.....	57 03	136 20	22	30 29.1	74 22.4	15 560	55 631
Ekaterinburg.....	56 50	60 38	24	11 00.8	71 58.4	16 578	50 942
Rude Skov.....	55 51	12 27	21	7 45.2	69 01.2	17 105	44 607
Kasan.....	55 50	48 51	24	8 53.5	70 07.6	17 310	47 517
Eskdalemuir.....	55 19	3 12	20	16 49.7	69 39.5	16 706	45 062
Meanook.....	54 37	113 20	24	27 17.7	77 73.7	12 866	59 984
Stonyhurst.....	53 51	2 28	24	15 05.3	68 41.7	17 276	44 281
Wilhelmshaven.....	53 32	8 09	11	11 28.2	67 30.7	18 110	43 747
Potsdam.....	52 23	13 04	23	6 56.9	66 36.5	18 565	42 920
Seddin.....	52 17	13 01	22	7 09.4	66 32.8	18 614	42 905

TABLE 2.—(Continued)

Observatory	Lat.	Long.	Yr	$D$	$I$	$H$	$Z$
Irkutsk (Zuja).....	52 28	104 02	20	1 02.3	71 06.6	19 277	56 337
De Bilt.....	52 06	5 11	24	10 38.3	66 52.7	18 372	43 024
Valencia.....	51 56	10 15	20	19 17.9	68 05.3	17 840	44 353
Bochum.....	51 29	7 14	21	10 10.4			
Kew.....	51 28	0 19	20	14 31.0	66 57.9	18 410	43 297
Greenwich.....	51 28	0 00	23	13 35.1	66 51.9	18 431	43 137
Uccle.....	50 48	4 21	16	12 28.4	66 02.8	18 971	42 703
Hermisdorf.....	50 46	16 14	13	6 58.2			
Prague.....	50 05	14 25	21	6 24.2			
Val Joyeux.....	48 49	2 01	22	12 31.5	64 39.6	19 661	41 517
Munich.....	48 09	11 37	13	9 06.2	63 04.6	20 623	40 609
			21	7 53.6			
O'Gyalla.....	47 53	18 12	18	5 21.9		20 917	
Odessa.....	46 26	30 46	10	3 35.9	62 26.9	21 707	41 606
Pola.....	44 52	13 51	22	8 28.0	60 12.8	22 090	38 591
Agincourt.....	43 47	79 16	24	7 05.8	74 44.4	15 752	57 733
Tiflis.....	41 43	44 48	13	3 09.1	56 51.1	25 217	37 612
Capodimonte.....	40 52	14 15	14			24 166	
Ebro (Tortosa).....	40 49	0 31	24	11 20.2	57 30.5	23 359	36 678
Coimbra.....	40 12	8 25	20	15 21.5	58 22.8	23 087	37 496
Cheltenham.....	38 44	76 50	22	6 27.7	70 57.6	19 020	55 115
Athens.....	37 59	23 42	08	4 53.0	52 11.7	26 197	33 613
San Miguel.....	37 46	25 39	20	19 24.9	60 26.0	23 123	40 759
San Fernando.....	36 28	6 12	24	13 23.5	53 46.8	25 016	
Kakioka.....	36 14	140 11	16	5 17.6	49 31.7	29 743	34 859
Tsingtau.....	36 04	120 19	20	4 12.9	52 07.0	30 817	39 610
Tucson.....	32 15	110 50	22	13 47.5	59 29.0	26 839	45 533
Luklapang.....	31 19	121 02	20	3 21.4	45 30.7	33 175	32 773
Dehra Dun.....	30 19	78 03	22	1 43.2	45 02.6	32 927	33 091
Helwan.....	29 52	31 20	19	1 30.6	41 09.6	29 947	28 175
Hongkong.....	22 18	114 10	24	0 23.8	30 42.8	37 294	22 155
Honolulu.....	21 19	158 04	22	9 57.1	39 24.5	28 794	23 658
Teoloyucan.....	19 45	99 11	22	9 09.9			
Toungoo.....	18 56	96 27	22	0 29.7	23 07.2	39 156	16 717
Alibag.....	18 38	72 52	22	0 12.6	25 05.0	36 967	17 303
Vieques.....	18 09	65 27	22	4 00.9	51 33.1	27 695	34 880
Antipolo.....	14 36	121 10	20	0 35.9	16 11.7	38 100	11 065
Kodaikanal.....	10 14	77 28	22	1 58.7	4 40.1	37 878	3 093
Batavia-Buitenzorg.....	6 11	106 49	24	0 52.9	32 04.3	36 821	23 072
St. Paul de Loanda.....	8 48	13 13	19	14 49.0			
Huancayo.....	12 03	75 20	24	8 01.7	0 54.6	29 755	395
Apia.....	13 48	171 46	24	10 19.2	30 07.5	35 249	20 453
Tananarive.....	18 55	47 32	14	8 25.2	53 37.9	22 484	30 532
Mauritius.....	20 06	57 33	23	10 49.2	52 33.7	22 982	30 018
Vassouras.....	22 24	43 39	23	11 42.8	15 53.7	24 407	6 950
Watheroo.....	30 19	115 53	24	4 18.3	64 05.2	24 750	50 941
Pilar.....	31 40	63 53	20	7 48.6	25 41.2	25 297	12 168
Toolangi.....	37 32	145 28	20	8 00.8	67 55.1	22 874	56 384
Christchurch.....	43 32	172 37	23	17 11.7	68 12.0	22 209	55 526
Orcadas.....	60 43	44 47	12	4 46.5	54 26.0	25 343	35 442

TABLE 3.—MAGNETIC ELEMENTS FOR EACH 10° OF LATITUDE AND LONGITUDE

Data obtained from charts (5) compiled at Royal Observatory, Greenwich, England, 1922. A ? indicates that the curves were too widely spaced to permit satisfactory interpolation.  $D$  = declination (east or west);  $I$  = inclination or dip (north-seeking pole down or up);  $H$  = horizontal intensity; *italics* indicate that  $D$  is to the west or that  $I$  is such that north-seeking pole is up. Unit of  $H$  =  $100\gamma = 10^{-3}$  gauss =  $10^{-3}$  cgsm.

Lat.	70° N.			60° N.			50° N.			40° N.			30° N.			20° N.			10° N		
Long.	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I
0° E.	?	18.7°	?	153	16.3°	72°	193	13.5°	65°	240	11.8°	57°	280	11.0°	43°	308	11.1°	26°	318	12.6°	5°
10 E.	?	10.6	?	157	9.7	71	197	9.0	64	244	8.2	55	286	7.9	42	316	7.9	23	325	8.7	2
20 E.	120	3.3	?	160	3.4	71	203	3.7	64	248	4.2	54	292	4.5	42	322	5.0	23	331	6.2	1
30 E.	120	2.6	?	163	2.1	71	208	1.0	64	253	0.9	54	299	1.6	41	330	2.4	22	337	3.7	2
40 E.	?	7.8	?	162	6.2	71	211	4.8	64	258	2.8	54	306	1.3	41	339	0.1	22	344	1.3	2
50 E.	?	13.0	?	160	10.0	71	212	7.2	65	265	4.8	55	313	3.2	42	344	1.8	23	352	0.8	3
60 E.	106	18.2	?	156	12.8	72	212	8.3	65	271	5.6	56	318	3.5	42	352	1.7	25	361	0.1	5
70 E.	98	?	?	150	14.1	73	212	8.8	66	275	5.7	56	324	2.8	43	361	0.4	26	372	1.9	5
80 E.	88	?	?	148	13.8	73	210	8.0	67	279	4.7	57	333	1.8	43	373	0.6	26	382	2.5	4
90 E.	80	?	80	137	10.7	74	210	6.2	67	282	?	57	342	?	43	383	0.5	26	395	1.5	4
100 E.	?	16.0	80	135	6.8	75	212	2.7	68	283	?	57	346	?	43	389	?	25	?	0.0	3
110 E.	?	10.0	80	137	0.4	75	216	1.3	68	284	1.8	57	344	1.4	43	384	?	25	?	1.2	3
120 E.	?	3.9	80	144	5.9	75	224	6.1	67	285	5.0	56	338	2.9	43	373	0.4	25	389	1.4	4



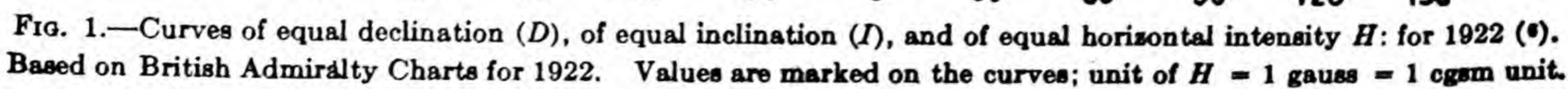
TABLE 3.—(Continued)

Lat.	70° N.			60° N.			50° N.			40° N.			30° N.			20° N.			10° N.		
Long.	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I
130 E.	83	1.0	80	157	?	74	232	9.4	66	285	6.8	55	326	3.8	42	360	0.9	26	379	1.5	5
140 E.	92	4.8	80	167	?	73	234	9.4	64	281	6.6	53	313	3.6	41	343	0.5	26	364	2.2	6
150 E.	100	0.0	?	174	8.0	72	235	6.7	62	274	4.2	52	300	1.6	41	325	1.0	26	348	3.7	7
160 E.	109	4.3	?	179	2.3	71	234	2.2	61	267	0.4	52	291	1.6	41	313	3.9	27	338	5.7	9
170 E.	114	10.2	?	182	2.6	70	230	2.6	61	261	3.9	52	283	5.5	42	304	6.8	29	330	8.0	12
180 E.	114	15.4	?	182	8.6	70	225	8.0	62	255	8.6	53	277	8.9	44	299	9.1	32	325	9.0	15
170 W.	110	21.2	?	177	15.0	71	220	13.5	63	250	12.5	55	274	11.3	46	296	10.2	35	324	9.0	18
160 W.	102	27.7	80	171	20.9	72	215	17.8	64	247	15.4	57	273	13.0	48	296	10.6	37	324	8.8	20
150 W.	93	35.0	80	163	26.0	73	208	21.4	66	245	17.7	59	275	14.1	50	299	10.9	38	325	8.8	22
140 W.	81	44.5	?	150	30.9	75	200	24.1	68	244	19.2	61	278	15.0	52	304	11.2	40	328	?	24
130 W.	67	54.6	?	130	35.6	77	190	25.9	70	240	19.8	62	282	15.2	53	310	11.6	41	332	9.1	25
120 W.	47	62.8	85	109	37.7	80	177	25.8	72	233	19.2	64	282	14.6	55	313	11.4	43	334	9.3	26
110 W.	33	70.0	?	87	32.6	82	156	22.3	75	221	16.8	67	280	13.3	57	314	10.7	44	336	9.3	28
100 W.	13	60.0	?	63	17.6	84	134	15.0	77	207	12.7	69	272	10.0	59	312	9.0	46	335	8.6	31
90 W.	19	67.3	?	47	3.0	85	121	2.1	78	192	5.0	71	259	6.2	62	304	6.4	49	329	7.1	33
80 W.	40	74.0	?	58	30.0	84	119	13.6	78	184	4.4	72	245	0.0	63	292	2.7	52	320	4.8	36
70 W.	58	73.0	85	76	41.7	82	127	24.0	77	185	13.3	71	235	6.3	63	275	2.3	52	305	0.7	38
60 W.	70	67.7	?	94	44.4	80	138	31.0	76	188	19.6	70	231	13.0	62	265	8.0	53	291	4.8	40
50 W.	82	59.0	?	111	43.2	78	152	32.5	74	195	24.0	68	233	18.0	60	264	13.6	51	286	10.9	40
40 W.	91	50.0	80	124	39.5	76	163	31.3	72	204	24.8	66	239	20.6	57	267	18.0	48	288	16.2	36
30 W.	100	40.3	?	134	34.9	75	173	28.0	70	215	22.8	63	248	20.0	54	277	?	43	?	19.0	28
20 W.	107	33.6	?	142	28.8	73	183	23.3	68	225	19.7	61	261	18.1	50	291	18.0	36	302	19.5	18
10 W.	?	26.3	?	148	22.2	72	189	18.6	66	233	15.7	58	273	14.6	46	301	14.7	30	311	16.8	10

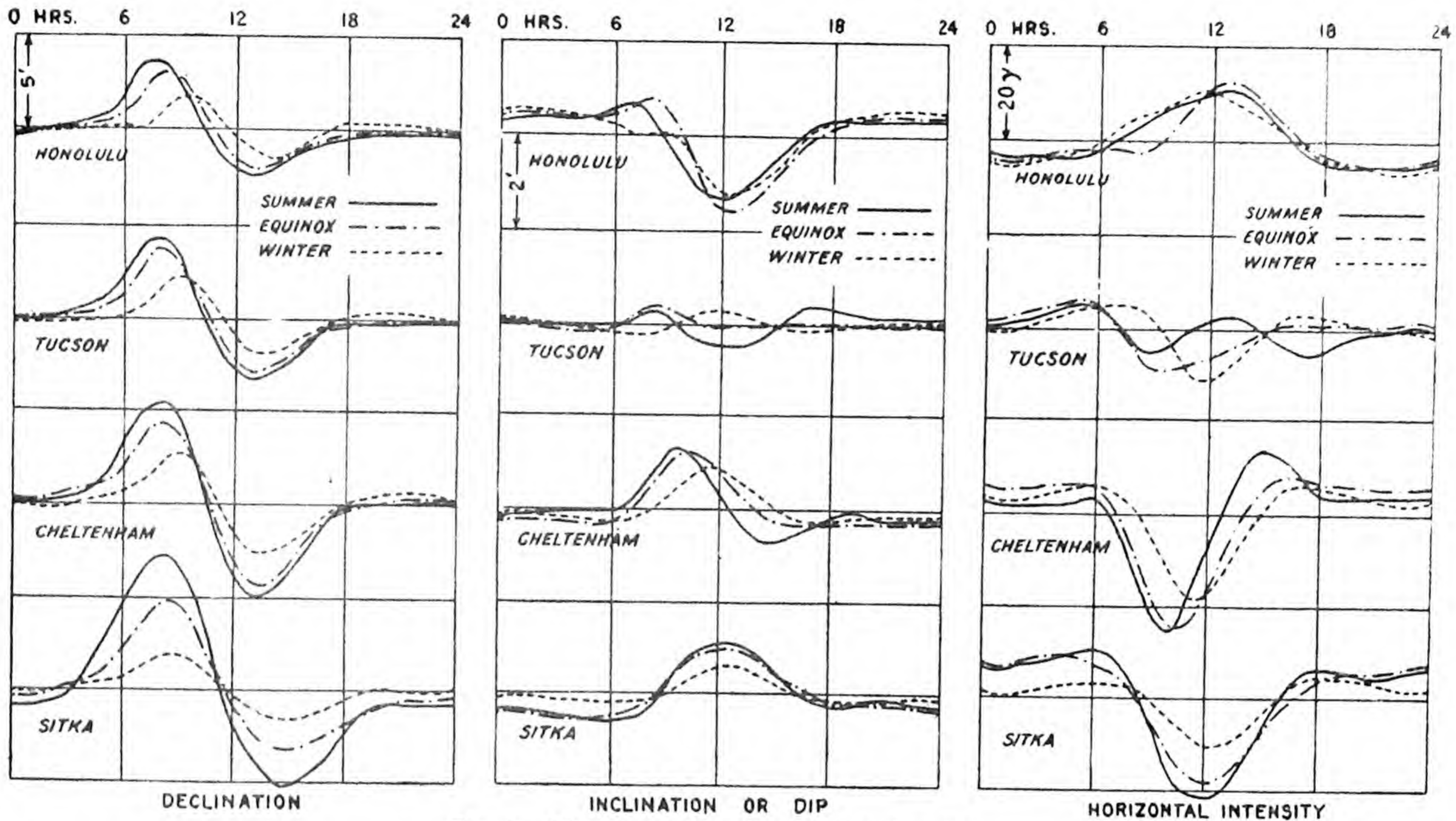
  

Lat.	0°			10° S.			20° S.			30° S.			40° S.			50° S.			60° S.		
Long.	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I
0° E.	290	16.1	17	246	20.4	33	209	25.1	44	188	28.0	51	181	28.2	55	184	25.2	59	189	22.1	62
10 E.	294	12.0	22	245	16.6	38	205	22.0	50	180	26.5	56	169	?	60	169	27.5	62	178	25.1	64
20 E.	297	8.2	23	245	12.9	41	203	18.4	52	172	23.7	59	158	27.7	62	159	29.0	65	168	27.3	?
30 E.	303	5.5	23	250	9.4	41	204	14.6	54	168	20.5	61	150	26.0	64	153	?	?	160	29.3	?
40 E.	313	2.2	22	258	5.7	41	208	10.7	54	169	17.0	61	?	24.4	65	?	29.8	?	?	32.3	?
50 E.	325	0.6	21	270	3.4	40	220	8.9	53	176	15.6	61	150	24.5	65	?	32.2	?	?	37.1	?
60 E.	338	2.0	19	285	5.0	38	234	10.3	52	188	18.0	61	161	27.1	65	?	36.0	?	?	41.6	70
70 E.	350	4.3	19	301	7.2	38	247	13.7	52	203	21.6	61	175	30.4	66	161	39.7	68	?	46.7	72
80 E.	360	4.6	20	316	8.0	38	261	14.0	52	215	22.5	62	186	32.5	67	166	42.5	70	?	51.1	74
90 E.	373	3.0	20	330	5.7	39	276	11.0	53	224	19.5	62	188	30.4	68	162	42.1	73	141	54.3	76
100 E.	384	0.6	20	342	2.3	38	290	6.5	53	233	13.3	63	188	24.6	70	148	38.6	75	124	54.7	78
110 E.	389	1.4	19	353	0.4	37	303	1.9	52	244	7.4	63	188	15.2	72	135	30.6	77	105	52.3	?
120 E.	387	2.4	17	360	2.2	36	314	0.6	51	253	2.4	63	190	7.3	72	127	18.5	78	87	43.2	?
130 E.	382	3.0	16	364	3.5	34	325	3.1	49	265	2.0	62	197	0.4	71	128	5.9	78	?	25.0	?
140 E.	?	4.0	14	367	4.8	32	332	5.2	48	275	5.5	61	207	5.5	70	137	4.0	77	?	0.0	?
150 E.	?	5.3	12	?	6.3	31	336	7.1	46	284	8.2	60	219	9.7	69	151	12.1	76	86	14.4	?
160 E.	360	6.9	10	?	7.9	28	338	9.0	44	291	10.5	58	231	13.3	67	166	16.6	75	100	21.6	?
170 E.	355	?	?	?	8.9	25	339	10.2	43	295	12.3	56	242	15.5	65	182	19.2	73	118	26.9	80
180 E.	352	?	4	360	9.3	23	340	10.7	40	297	13.1	54	251	16.5	63	195	20.4	71	133	28.8	78
170 W.	349	?	0	?	9.4	21	338	11.0	38	300	13.5	52	258	16.7	62	204	20.7	70	145	29.6	77
160 W.	346	?	1	?	9.3	19	333	11.1	36	302	13.6	50	264	16.7	60	211	20.8	68	158	29.7	75
150 W.	?	?	3	344	9.3	17	327	11.1	35	303	13.6	48	268	16.8	58	218	20.9	66	169	29.8	74
140 W.	?	?	4	337	9.4	16	322	11.2	33	302	13.6	46	272	16.8	57	227	21.3	65	182	30.1	72
130 W.	?	?	6	333	9.5	15	318	11.3	32	301	13.8	45	274	17.1	55	237	22.0	64	196	31.4	71
120 W.	?	?	7	330	9.7	13	314	11.6	30	298	14.2	43	275	17.9	53	248	23.1	62	212	32.7	69
110 W.	341	9.1	9	324	10.0	11	309	12.0	28	294	15.2	41	276	19.2	52	255	24.4	60	226	33.1	67
100 W.	337	9.4	12	318	10.6	8	302	12.9	25	289	16.3	38	277	20.5	48	262	25.4	57	239	32.0	64
90 W.	330	8.8	15	310	10.5	4	292	13.2	21	282	16.6	35	?	20.5	45	268	24.4	54	250	28.8	61
80 W.	320	6.6	18	298	9.0	0	280	11.3	16	271	15.0	30	269	18.3	41	270	21.1	50	256	25.0	58
70 W.	308	2.7	23	286	5.0	6	270	7.4	11	259	10.3	26	260	13.6	37	265	16.6	47	257	20.0	56
60 W.	295	3.8	25	278	0.9	8	260	1.0	8	248	3.7	22	250	6.7	34	258	10.1	44	?	13.6	53
50 W.	291	9.2	25	272	8.2	8	250	6.8	8	237	4.8	22	239	1.0	33	250	3.1	43	249	7.0	53
40 W.	291	15.3	20	268	15.1	2	243	14.5	12	228	12.3	26	227	9.1	35	237	4.6	44	237	0.4	53
30 W.	290	19.5	11	263	20.0	5	236	19.8	21	218	18.6	32	214	15.7	39	224	11.5	47	224	6.4	54
20 W.	289	21.1	1	257	22.6	15	227	23.7	30	209	23.6	38	203	21.0	45	209	17.0	51	211	12.7	57
10 W.	289	19.6	8	250	23.1	25	218	25.6	37	198	27.0	45	192	25.4	51	197	21.7	55	199	17.8	59








 FIG. 2.—Diurnal variations at selected stations (<sup>10</sup>).

Data are based on average values for stormless days. Time is measured from local mean noon;  $1\gamma = 10^{-6}$  gauss =  $10^{-6}$  cgs unit.

 TABLE 4.—SECULAR CHANGES IN DECLINATION ( $D$ ) AT VARIOUS PLACES, AND OVER LONG PERIODS (<sup>10</sup>)

For recent variations, see Table 5; south and west values are printed in *italics*

Lat.	51° 28'	44° 55'	37° 48'	23° 07'	14° 36'	12° 04'	22° 54'	33° 56'
Long.	0 19	67 00	122 27	82 22	120 58	77 08	43 10	18 29
Place	London, England	Eastport, Maine	San Francisco, California	Havana, Cuba	Manila, P. I.	Callao, Peru	Rio de Janeiro, Brazil	Cape Town, S. Africa
Year	$D$							
1540	7.2°							
1560	9.6							
1580	10.9							
1600	10.1							1.0°
1620	7.3	19.0°						1.5
1640	3.3	18.5						4.0
1660	0.6	17.5					12.1°	6.4
1680	3.9	16.0					11.8	8.9
1700	7.1	14.5					11.3	11.5
1720	11.0	13.1		4.0°		6.7°	10.6	14.0
1740	15.3	12.4		5.0		7.7	9.7	16.8
1760	19.6	12.3		5.8	0.1°	8.6	8.5	19.4
1780	22.7	12.4	12.6°	6.3	0.0	9.4	7.1	22.8
1800	24.1	13.2	13.6	6.5	0.1	10.0	5.5	25.0
1820	24.1	14.7	14.6	6.3	0.2	10.4	3.5	27.1
1840	23.2	16.3	15.4	6.0	0.3	10.6	1.2	29.0
1860	21.5	18.0	16.1	5.2	0.5	10.5	1.5	30.0
1880	18.7	18.8	16.5	4.0	0.7	10.3	4.4	29.8
1900	16.5	19.3	16.9	3.1	0.9	9.9	7.7	28.6
1910	15.7	20.0	17.6	3.0	0.8	9.2	9.5	27.5
1920	14.1	20.8	17.9	3.4	0.7	8.5	11.2	26.1

 TABLE 5.—SECULAR CHANGES IN MAGNETIC ELEMENTS AT VARIOUS OBSERVATORIES: 1905 TO 1925 (<sup>10</sup>)

$Z$  = total intensity,  $D$  = declination (east or west),  $I$  = inclination (north-seeking pole down). West values are printed in *italics*.  $\Delta$  = algebraic excess above value in column 1905; e.g., at Sitka in 1915,  $Z = 58\,797 - 659 = 58\,138$ ,  $D = 29^\circ 59.1' + 24.1' = 30^\circ 23.2'$ ,  $I = 74^\circ 43.2' - 16.7' = 74^\circ 26.5'$ . Unit of  $Z = 1\gamma = 10^{-6}$  gauss =  $10^{-6}$  cgs unit.

Year		1905	1910	1915	1920	1925
Place		Value	$\Delta$			
Sitka.....	$Z$	58 797	-371	-659	-997	-1 177
57° 03' N.....	$D$	29° 59.1'	+17.3'	+24.1'	+29.1'	+28.1'
135° 20' W.....	$I$	74° 43.2'	-11.0'	-16.7'	-21.1'	-21.0'
Greenwich.....	$Z$	47 274	-34	-171	-252	-424
51° 28' N.....	$D$	16° 09.9'	-28.7'	-1° 13.4'	-2° 01.3'	-2° 59.9'
0° 00'.....	$I$	66° 55.9'	-3.3'	-4.1'	-2.3'	-4.4'
Toronto.....	$Z$	61 730	-309	-935	-1 439	
43° 40' N.....	$D$	5° 42.2'	+21.7'	+48.3'	+1° 03.2'	
79° 24' W.....	$I$	74° 34.3'	+4.2'	+8.6'	+10.3'	
Cheltenham.....	$Z$	59 878	-282	-896	-1 380	-1 895
38° 44' N.....	$D$	5° 17.8'	+23.6'	+46.2'	+1° 00.7'	+1° 21.4'
76° 50' W.....	$I$	70° 25.4'	+10.0'	+21.4'	+30.0'	+35.1'
Tucson.....	$Z$	53 669	Values for 1910	-374*	-712*	-1 072*
32° 15' N.....	$D$	13° 25.8'	+16.7'	+22.2'	+22.2'	+19.5'
110° 50' W.....	$I$	59° 19.6'	+5.1'	+8.0'	+11.0'	+11.0'
Honolulu.....	$Z$	38 168	-258	-587	-827	-1 006
21° 19' N.....	$D$	9° 21.7'	+8.0'	+19.9'	+31.5'	+40.1'
158° 04' W.....	$I$	40° 05.0'	-17.8'	-35.9'	-39.9'	-39.1'
Vieques.....	$Z$	44 795	-61	-85	-213	
18° 09' N.....	$D$	1° 38.3'	+42.3'	+1° 31.8'	+2° 07.8'	
65° 27' W.....	$I$	49° 17.0'	+35.0'	+1° 28.9'	+2° 05.7'	

\* Algebraic excess over value for 1910.

**Earth Currents.**—It is not practicable to do more than to indicate the order of magnitude of earth currents. At the observatory del Ebro, Tortosa, Spain, the horizontal electrical potential gradient in the earth was measured over a distance of 1.28 km in a north-south line, and over a distance of 1.40 km in a west-east line. The average of observations extending over 4 yr (1914–18) gave as the gradient along the N.-S. line 0.204 volt per km,

current (+) from N. to S., and along the W.-E. line 0.114 volt per km, current (+) from W. to E.

**Aurora.**—Auroral activity is confined largely to two zones of the atmosphere situated at an angle of about 20° to the magnetic polar axis. The lower edge of the aurora is sharply bounded; the height of this boundary appears to vary from 70 to 300 km, with a maximum number at about 115 km.



## LITERATURE

(For a key to the periodicals see end of volume)

- (<sup>1</sup>) Angenheister, *B96*, Vol. 15. (<sup>2</sup>) Auerbach, *B90*, Vol. 4. (<sup>3</sup>) Bauer, *268*, 25: 145; 20. (<sup>4</sup>) Bauer, *268*, 28: 1; 23. (<sup>5</sup>) British Admiralty Charts. (<sup>6</sup>) Bur. Central Magn. Terr. *Atlas magnétique*. Paris, Maurin, 1905. (<sup>7</sup>) Chree, *Encycl. Brit.*, 11th ed., 17: 353; 10. (<sup>8</sup>) Dyson and Furner, *520*, *Geophys. Suppl.*, 1: No. 3; 23. (<sup>9</sup>) Fleming, *Trans. Sect. Terr. Mag. Elec., Intern. Geophys. Union*, Madrid, 1925. Bull. 5. (<sup>10</sup>) Hazard, *217*, No. 117; 25. (<sup>11</sup>) Nippoldt, in Müller-Pouille, *Lehrbuch*

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## ACOUSTICS

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Physical aspects of audition.

Sound-generators.

Detection and measurement of sound.

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Ermittelung und Messung des Schalles.

Durchlassen, Reflexion, Wiederhall und Absorption des Schalles.

Schall-Geschwindigkeit

## INDICE COMPLETO PAGHE

Principi fisici dell'audizione 450

Produzione del suono . . . 453

Percezione e misura del suono . . . . . 457

Trasmissione, riflessione, riverberazione e assorbimento del suono . . . . . 458

Velocità di propagazione del suono . . . . . 461

## PHYSICAL ASPECTS OF AUDITION

H. FLETCHER

For general bibliography of speech and hearing, see (<sup>6</sup>)

## SYMBOLS AND DEFINITIONS

d.v. Double (or complete) vibration(s).

*E* Physical intensity of a sound = power (energy per second) it transmits per a unit of area normal to direction of propagation.

*N* Frequency = number of d.v. per unit of time.

*P* Amount by which the r.m.s. pressure exceeds the static pressure;  $P_0$  = threshold value of *P* for an average normal ear; it depends upon *N*;  $P_m$  = value of *P* required for audition in presence of a masking tone.

r.m.s. Root-mean-square; r.m.s. pressure = square root of the time average of (pressure)<sup>2</sup>.

*S* Sensation level.

sen Sensation unit.

*t* Time.

v.p.s. Vibrations per second; 1 v.p.s. = 1 d.v. per sec.

$\varphi$  Phonic level.

*Masking of a tone* (*A*) by another (*B*) means the difficulty in distinguishing *A* when sounded simultaneously with *B*. It is expressed by the difference in phonic level between  $P_m$  and  $P_0$ , this equals  $20 \log_{10} (P_m/P_0)$  sen. (See Figs. 2, 3, 4.)

*Phonic level* of *P* above the fixed datum corresponding to  $P'$  is  $\varphi_P = 20 \log_{10} (P/P')$  sen. In this section  $P'$  is taken as 1 dyne  $\text{cm}^{-2}$ . (Cf. Sensation unit.)

*Sensation level* (*S*) measures the auditory intensity of sound; it is the excess of the phonic level above that of  $P_0$ . For a pure tone,  $S = \varphi_P - \varphi_{P_0} = 20 \log_{10} (P/P_0)$  sen.

*Sensation unit* (sen) is defined as that fractional change in intensity which is just perceptible by the ear. Throughout the range of audition, it is found that if the sensation being experienced is that corresponding to  $P = P_1$ , then the smallest perceptible change is approximately  $1/20$  of that caused by increasing *P* from  $P_1$  to  $10P_1$ . Hence in the range  $P_1$  to  $P_2$  there are  $20 \log_{10} (P_2/P_1)$  sen. It is convenient to regard this relation as extending indefinitely, irrespective of the range of audition, and to regard each value of *P* as corresponding to a phonic level of  $20 \log_{10} (P/P')$  sen above some convenient fixed datum ( $P'$ ) which is independent of the auditor and audition. (Cf. (<sup>5</sup>).)

*Sensitivity* of the ear is inversely proportional to  $P_0$ ; the unit is so chosen that the sensitivity =  $1/P_0$ .

*Threshold value* ( $P_0$ ) of *P* for any given auditor and tone is that least value of *P*, in the ear canal, which produces an audible sound of that tone.

TABLE 1.—SENSITIVITY OF THE EAR

See also Vol. I, p. 94

*Absolute Sensitivity* =  $1/P_0$ .—*Differential sensitivity* is the reciprocal of the least perceptible fractional change ( $\Delta E/E$ ,  $\Delta N/N$ ) in *E* or *N*. Sensitivity in recognition of pitch may be taken as the reciprocal either of the time the tone must persist, or of the total number of d.v. that must reach the ear, in order that the tone shall be recognized.

Unit of  $N = 1$  v.p.s.; of  $P_0 = 1$  dyne/ $\text{cm}^2$ ; of  $t = 1$  sec; of  $S = 1$  sen.

*Limits of Audibility* (<sup>6</sup>).—Lower limit varies from  $N = 8$  to 40; upper, from  $N = 12\ 000$  to 35 000.



Absolute sensitivity (9, 13, 20); see also Fig. 1.

$N$ .....	64	128	256	512	1024	2048	4096
$P_0$ .....	0.120	0.021	0.0039	0.0010	0.00052	0.00041	0.00042

Differential sensitivity for monaural reception of successive tones (12, 14).

$\Delta E/E$  depends upon both  $S$  and  $N$ , and is given by the empirical equation  $\Delta E/E = (\Delta E/E)_\infty + \{(\Delta E/E)_i - (\Delta E/E)_\infty\} \times 10^{-rS/10}$ , where  $(\Delta E/E)_\infty = 126/\{80N^{0.5} + N\} + 0.000015N$ ,  $(\Delta E/E)_i = 0.3 + 0.003N + 193/N^{0.8}$ , and  $r = 0.244 \times 10^6/\{358000N^{0.126} + N^2\} + 0.65N/\{3500 + N\}$ .

$\Delta N/N$  varies with  $S$  about as  $\Delta E/E$  does. For  $S = 40$  sen,  $\Delta N/N$  varies with  $N$  thus:

$N$ , v.p.s.....	64	128	256	512	768 to 4096
$\Delta N/N$ , %.....	0.93	0.59	0.4	0.32	0.3

Pitch Recognition (1).— $t$  and d.v. = least duration of the tone, and smallest number of d.v. received, consistent with recognition of the tone.

$E$	Weak			Medium		
$N$ .....	128	384	512	256	384	512
$t$ .....	0.0946	0.0627	0.0579	0.0691	0.0445	0.0427
d.v.....	12.1	24.1	29.6	17.6	17.1	21.8

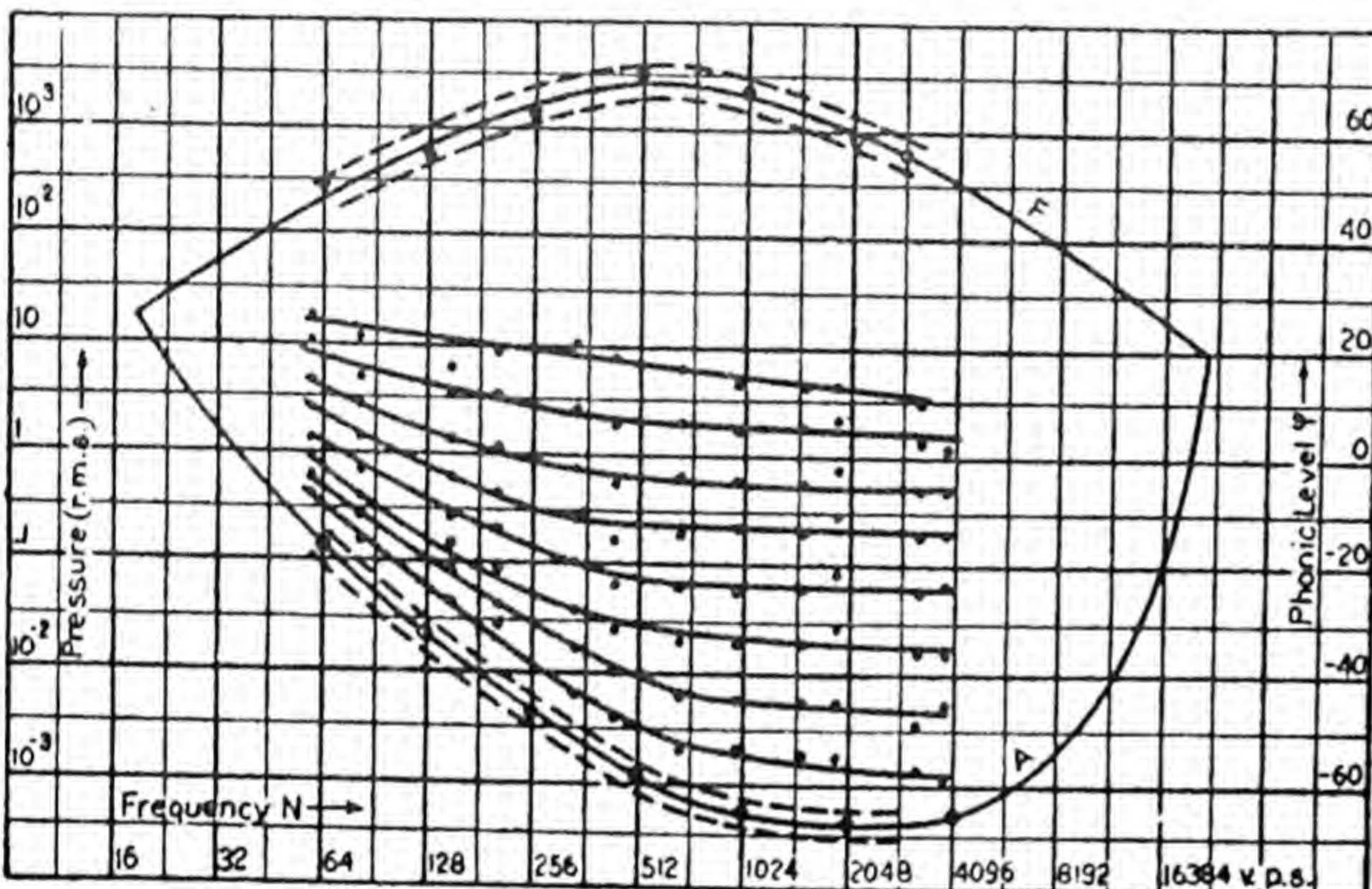


FIG. 1.—Phonic levels ( $\phi$ ) for equality of loudness of pure tones.

Threshold values of audibility are shown by curve  $A$  (weighted mean (7, 9, 13), pitch limits range (9) from  $N = 8$  to 40 and from  $N = 12000$  to 35000), of feeling, by curve  $F$  (18); half of observations lie between the dotted curves. Interior curves are contour lines of equal loudness, reference tone being  $N = 700$  v.p.s.; each point is average of 3 observations by each of 22 observers; distance from curve  $A$  measures the sensation level.  $\phi$  = phonic level, datum = 1 dyne/cm<sup>2</sup>, unit = 1 sen; unit of pressure = 1 dyne/cm<sup>2</sup>.

Loudness (8, 11, 16).—Until recently it was thought that the loudness of a tone is measured by its sensation level, but there is not a strict proportionality between these two quantities. Contour lines of equal loudness for pure tones show that tones below 1000 v.p.s. increase in loudness more rapidly than do tones of higher frequency. (See Fig. 1.)

Localization of Pure Tones (17).—If  $100 \text{ v.p.s.} \leq N \leq 1000 \text{ v.p.s.}$ , then, approximately,  $\theta = \psi/(0.8 + 0.0034N)$ , if unit of  $N = 1 \text{ v.p.s.}$ ;  $\theta$  = angle the apparent direction of the source makes with median plane of the observer;  $\psi$  = angular phase difference of the tone at the two ears.  $\theta$  and  $\psi$  must be expressed in the same unit; positive direction of  $\theta$  is from the front towards the ear of the leading phase.

Miscellaneous Aural Data.—Minimum audible power =  $4(10)^{-6}$  microwatt/cm<sup>2</sup> (9, 13, 20). Ear canal: Length = 2.1 to 2.6 cm, volume = 1 cm<sup>3</sup>, area of open end = 0.33 to 0.50 cm<sup>2</sup>. Drum. Diameter = 0.85 cm vertical, 1.00 cm horizontal; area = 0.65 cm<sup>2</sup>.

Hammer: Length = 0.8 to 0.9 cm; weight = 23 mg. Anvil weighs 25 mg. Stirrup weighs 3 mg (10, 21). Mechanical impedance of drum (7) for  $N = 200$  to 4000 v.p.s. = 20 to 30 dyne/(cm per sec); that is, a value of  $P$  corresponding to an r.m.s. periodic force of 20 or 30 dyne is required to impart to the drum an effective r.m.s. velocity of 1 cm/sec, the effective

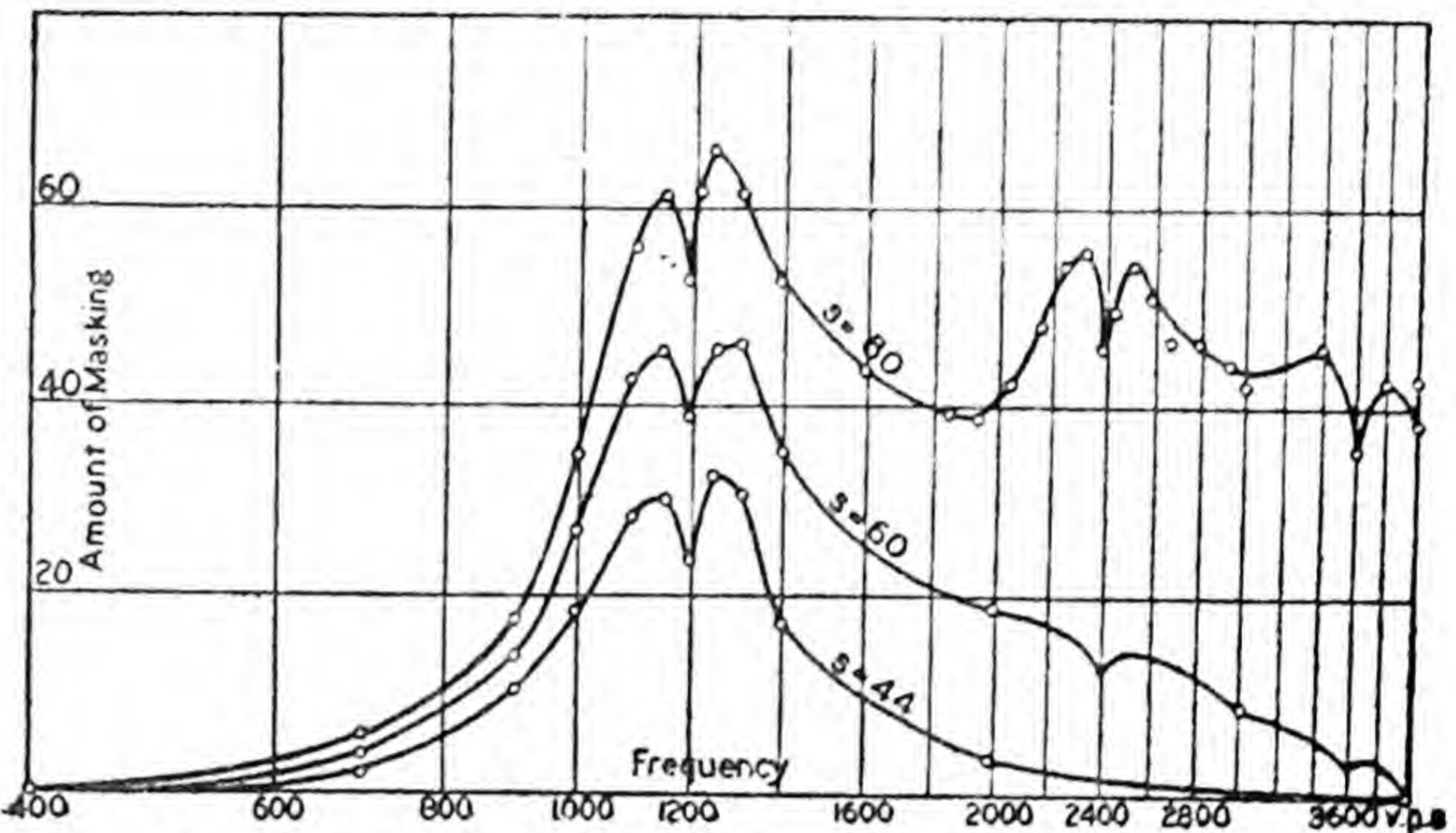


FIG. 3.—Masking of tones of various frequencies by one of  $N = 1200$  v.p.s. and of sensation level = 44, 60 or 80 sen: Both tones sounded in same ear (19).

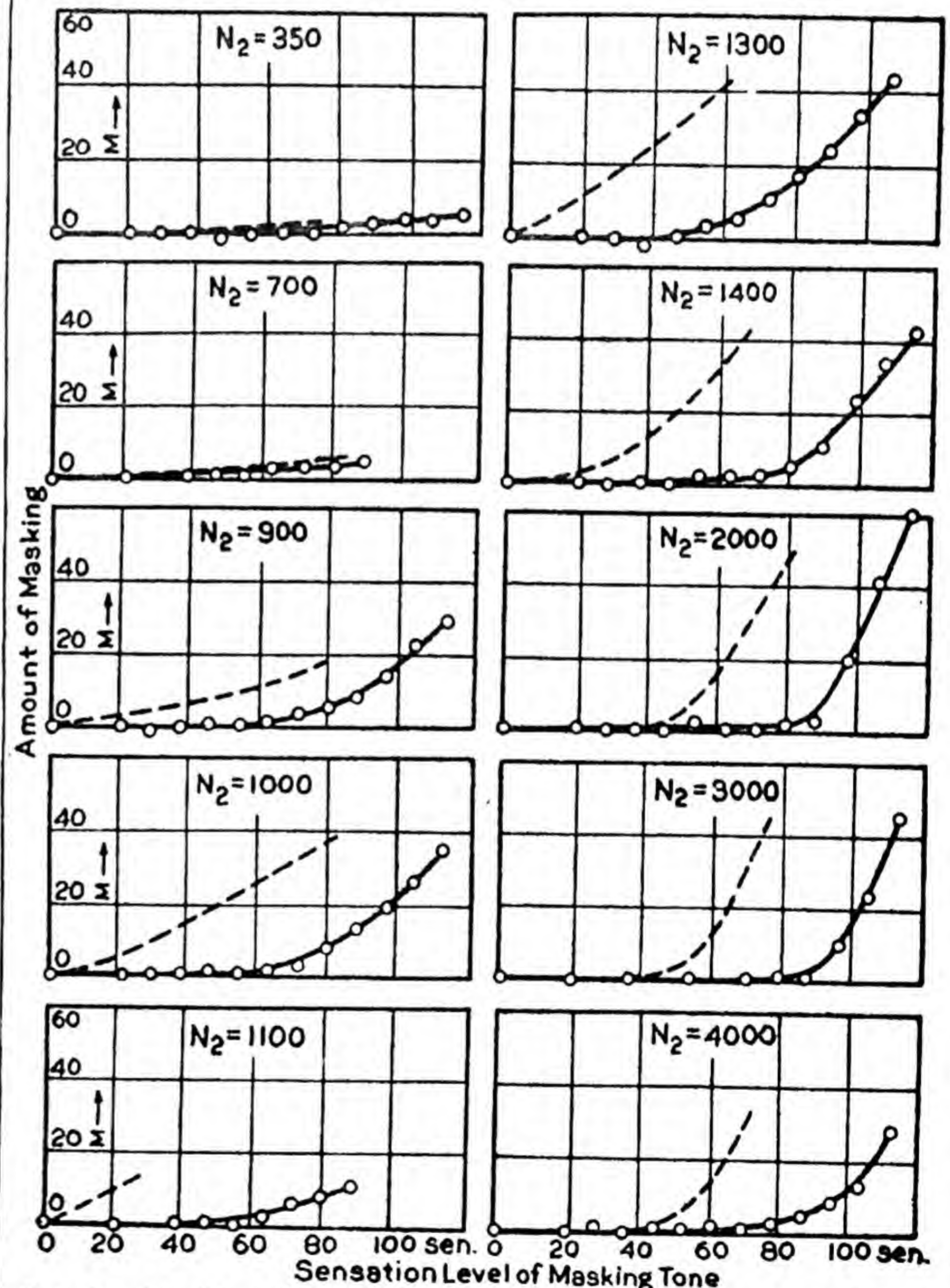


FIG. 4.—Masking of tones  $N_2$  by tones of  $N = 1200$  v.p.s. of various intensities: Tones sounded in opposite ears (19).

Tones introduced by telephone receivers. Dotted lines are from Fig. 2. Attenuation introduced by the skull from ear to ear is such that in monaural reception the phonic levels at the two ears differ by 40 or 50 sen.  $M$  = amount of masking. Unit of  $N_1 = 1 \text{ v.p.s.}$ ; of  $M$  and of sensation level = 1 sen.



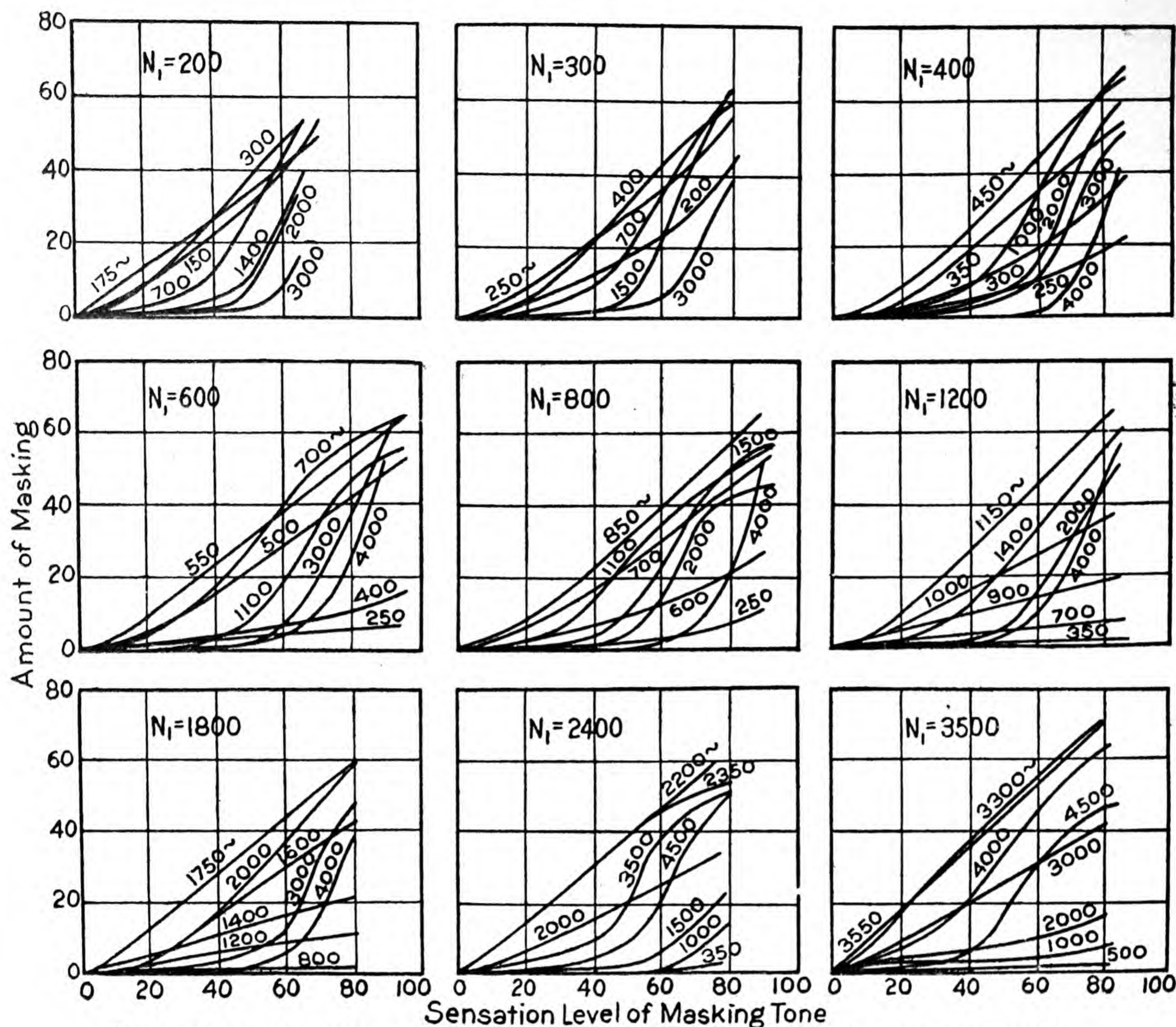


FIG. 2.—Masking of tones  $N_1$  by tones of various frequencies and intensities: Both tones sounded in same ear (19). Frequency ( $N$ ) of masking tone is marked on curve; unit of  $N$  and  $N_1 = 1$  v.p.s.; of masking and sensation level = 1 sen.

velocity ( $\bar{v}$ ) being defined as  $v = \frac{1}{A} \int_0^A v da$ ,  $A$  being the area of the drum and  $da$  being an element of area at which the velocity is  $v$ .

**Recognition of English Speech (4).**—In order that at least 50% of the spoken syllables shall be recognized: (1)  $S$  must be  $\geq 25$  sen if the sound is undistorted. (2) If  $S = 60$  to 80 sen and the sound is distorted either by the removal of all frequencies above  $N = N_1$ , or of all below  $N = N_2$ , then  $N_1$  must be  $> 1200$  v.p.s. and  $N_2 < 1800$  v.p.s. (See Fig. 5.)

**Speech Power (7).**—Mechanical speech power delivered by average speaker = 10 microwatt; if exclude silent intervals, it is 14 microwatt. Peak power frequently rises to 1000 microwatt. For unaccented vowels, average power in the particular cycle carrying the maximum energy is 35 microwatt; for accented vowels, it is 105 microwatt; instantaneous peak powers are 16 times average power (15). Telephonic speech power = electrical power output of a commercial telephone subset during a normal telephone conversation. For individual variations, see Fig. 6; for distribution of power among the tones, see Fig. 7.

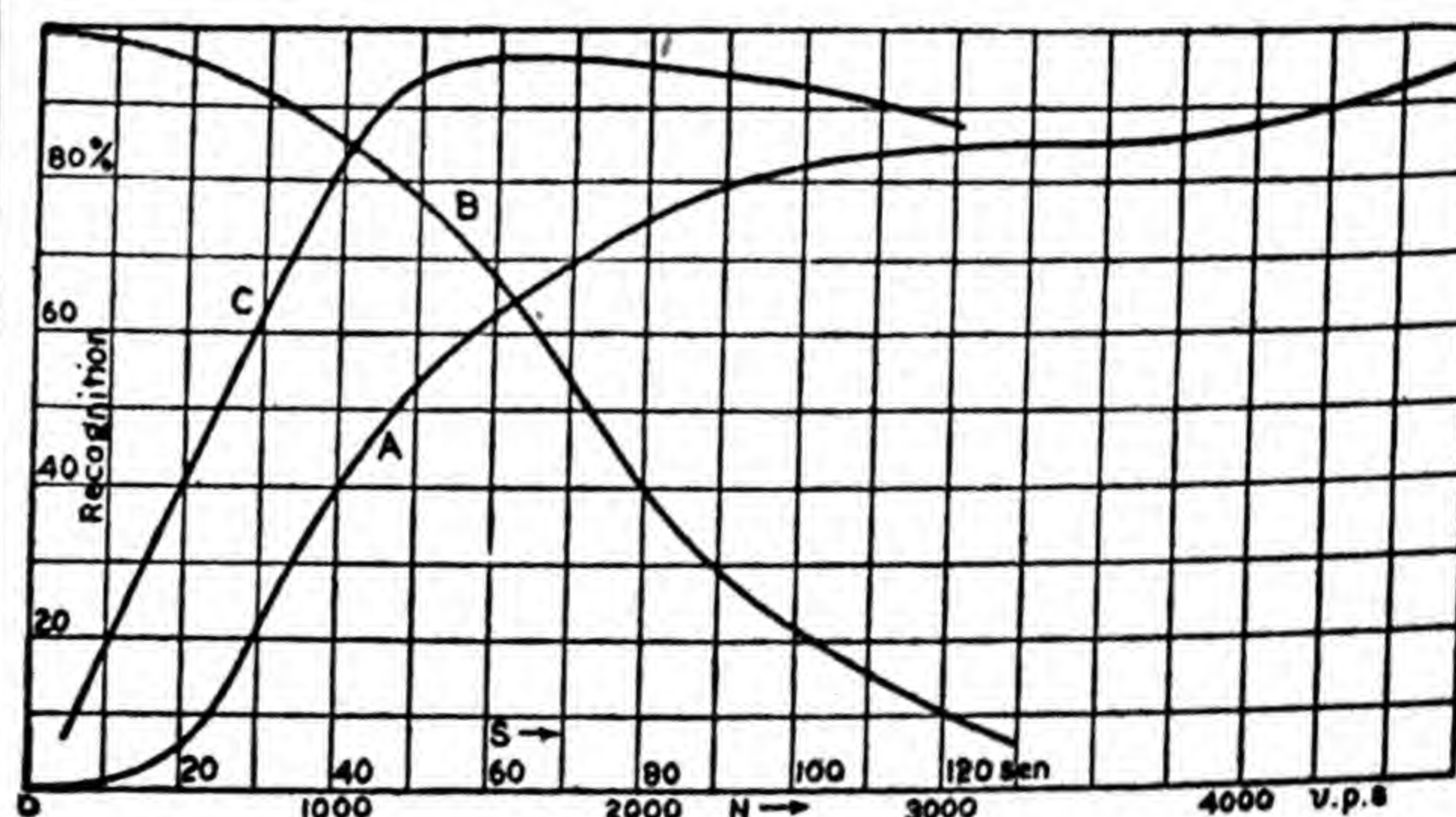


FIG. 5.—Recognition of English speech (4). Recognition = relative number of syllables recognized. For curve A, all frequencies above  $N$  are eliminated; for B, all those below  $N$ ; C shows effect of sensation level ( $S$ ) upon recognition of the undistorted sounds. For A and B,  $S = 60$  to 80 sen.



TABLE 2.—RELATIVE FREQUENCY ( $F$ ) OF OCCURRENCE OF SOUND ELEMENTS OF ENGLISH SPEECH (3)

Sound = sound element; Key = English word containing the sound; unit of  $F$  = 1 % of total

Sound	Key	$F$	Sound	Key	$F$
a	top	3.3	h		1.81
ā	tape	1.84	j		0.44
á	tap	3.95	k		2.71
e	ten	3.44	l		3.74
ē	eat	3.12	m		2.78
er	term	0.63	n		7.24
i	tip	8.53	ng	hang	0.96
ī	dike	1.59	p		2.04
o	ton	6.33	r		6.88
ō	tone	1.63	s		4.55
ó	talk	1.35	sh	shell	0.87
u	took	0.71	th	tooth	0.37
ū	tool	1.89	th	then	3.43
ou	our	0.59	t		7.13
b		1.81	v		2.28
ch	chalk	0.52	w		2.08
d		4.31	y		0.60
f		1.84	z		2.97
g		0.74	Total		100.00

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Bode, *Psychologische Studien*, (Wundt), 2: 293; 07. (2) Crandall and MacKenzie, 2, 19: 221; 22. (3) Dewey, *The relative frequency of English speech sounds*, Cambridge, Harvard Univ. Press, 1923. (4) Fletcher, 143, 193: 729; 22. (5) Fletcher, 143, 194: 280; 23. (6) Fletcher, 143, 194: 323; 23. (7) Fletcher, *Bell System Tech. J.*, 4: 375; 25. (8) Fletcher and Steinberg, 2, 24: 306; 24. (9) Fletcher and Wegel, 2, 19: 553; 22. (10) Howell, *Text-book of physiology*, Philadelphia, Saunders, 1924. (11) Kingsbury, 2, 29: 588; 27. (12) Knudsen, 2, 21: 84; 23. (13) Kranz, 2, 21: 573; 23. (14) Riesz, Bell Telephone Laboratories, N. Y., 0. (15) Sacia, Bell Telephone Laboratories, N. Y., 0. (16) Steinberg, 2, 26: 507; 25. (17) Stewart, 2, 15: 425, 432; 20. (18) Wegel, *Bell System Tech. J.*, 1: 56; 22. (19) Wegel and Lane, 2, 23: 266; 24. (20) Wien, 278, 97: 1; 03. (21) Wrightson, *Enquiry into the mechanism of the internal ear*, New York, Macmillan, 1918.

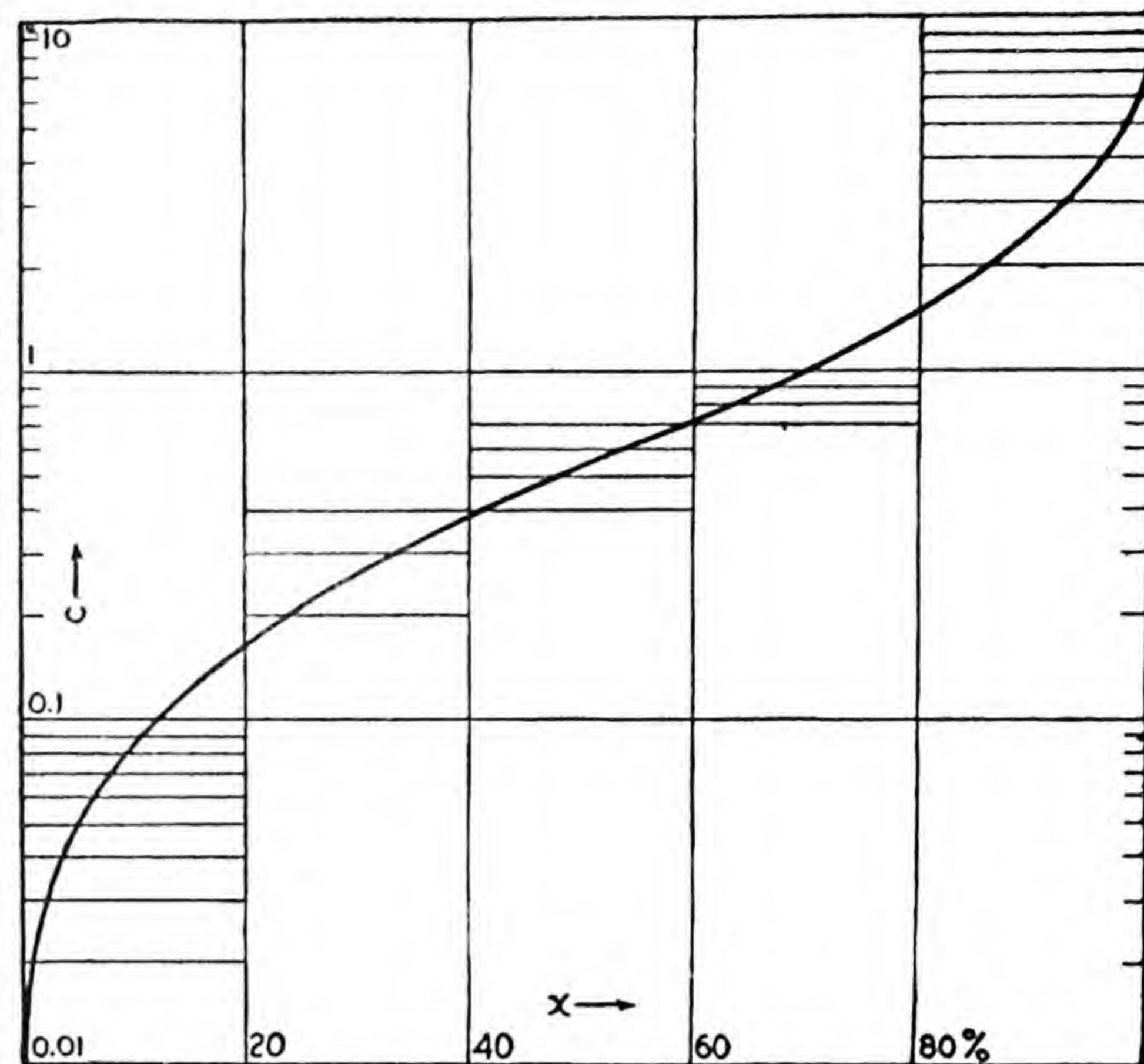


FIG. 6.—Variation in telephonic speech power of individuals (7).  $x$  = percentage of speakers having telephonic speech power  $\geq CA$ , where  $A$  = average power of all speakers.

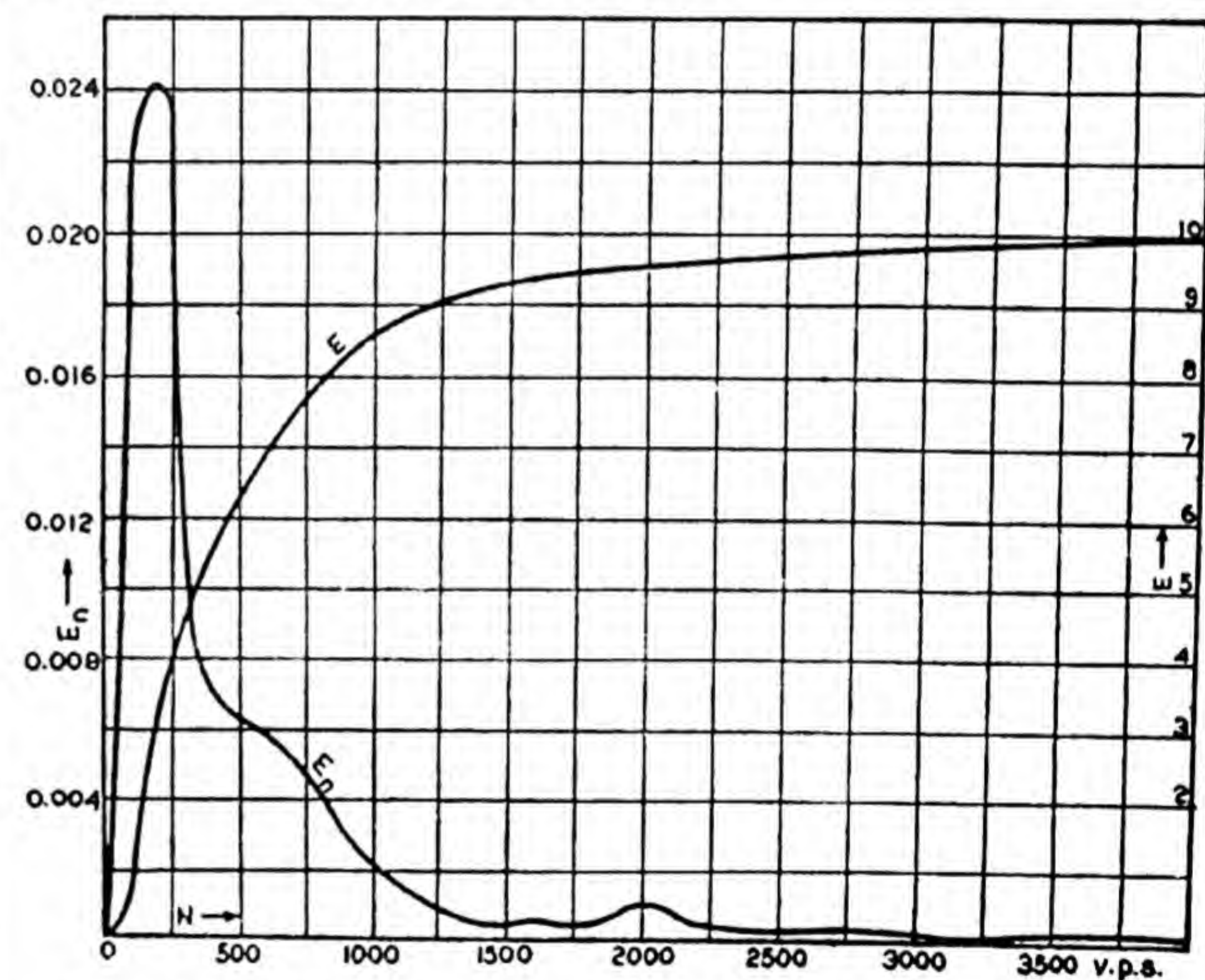


FIG. 7.—Distribution of power in average spoken English (2). Total power carried by all the tones from  $N = 0$  to  $N = n'$  is  $E = \int_0^{n'} E_n dn$ , where  $E_n dn$  = power carried by the tonal region  $N = n - \frac{1}{2}dn$  to  $N = n + \frac{1}{2}dn$ . Unit of  $E_n$  = 1 microwatt per v.p.s.; of  $E$  = 1 microwatt; of  $n, n', N$  = 1 v.p.s.

## SOUND-GENERATORS

F. R. WATSON

### CONTENTS

	PAGE
Definitions and symbols.....	453
Sound-generators.....	454
Means for stabilizing the frequency of an oscillating electric circuit.....	456

### DEFINITIONS AND SYMBOLS

**Amplitude.**—The amplitude of the oscillation of a point is its extreme departure from that condition of rest about which the

oscillations occur. If the departure ( $y$ ) at the time  $\tau$  satisfies the equation  $y = A \sin (n\tau + \epsilon)$ ,  $A$  is the amplitude.

**Frequency.**—The frequency of an oscillation is the number of vibrations per unit of time.

**Period.**—The period of an oscillation is the time required for one vibration; it is the reciprocal of the frequency.

**Vibration.**—In each interval between successive returns of the body to exactly the same phase of its motion, it executes a single vibration. For example, from the instant a pendulum bob passes from left to right through the lowest point of its arc to the



next instant in which it passes in the *same* direction (left to right) through the same point is the interval occupied by a single vibration of the pendulum.

$a$	Thickness in the plane of vibration.
$E$	Young's modulus of elasticity.
$F$	Tensile force.
$l$	Length.
$N$	Frequency.
$N_i, N_o, N_t$	Frequency for ideal case, at $0^\circ\text{C}$ , at $t$ , $^\circ\text{C}$ .
$p$	Pressure.
$r, r_o$	Radius, value of $r$ at $0^\circ\text{C}$ .
$t$	Temperature, $^\circ\text{C}$ .
v.p.s.	Vibrations per second.
$\rho, \rho_o$	Density, value of $\rho$ at $0^\circ\text{C}$ .
$\sigma$	Mass per unit of length.

Other symbols will be defined where used.

## SOUND-GENERATORS

Of the sound-generators, exclusive of musical instruments, only those that are most commonly used or that appear to be useful are considered here. They may be classified as follows:

I. Strings and strips: (A) Transverse vibrations: (1) Plucked string. (2) Ribbon loud-speaker. (B) Longitudinal vibrations: (3) Stretched wires. (4) Berger's hydrophone.

II. Rods and forks: (5) Tuning fork.

III. Plates and diaphragms: (A) Electromagnetic drive: (6) Telephone receiver. (7) Hewlett's generator. (8) Loud-speaker. (9) Fessenden's hydrophone oscillator. (B) Electrostatic drive: (10) Electrostatic transmitter. (C) Mechanical drive. (11) Piston-phone. (D) Piezoelectric generator: (12) Quartz ( $\text{SiO}_2$ ). (13) Rochelle salt ( $\text{KNaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$ ). (E) Free elastic vibrations: (14) Bell.

IV. Confined fluid: (15) Organ pipe. (16) Tonvariator. (17) Galton's pipe. (18) Singing tube. (19) Thermophone.

V. Free fluid: (20) Siren. (21) Diaphone. (22) Explosives.

Of the preceding generators, numbers 2 and 8 are especially suited for the intense emission of spoken sounds, and numbers 4, 9, 14, and 22 are suitable for the emission of sound under water.

Descriptions of other generators may be found in (3, 4, 5, 9, 10, 18, 47, 49, 54, 59).

1. *Plucked String* (3, 39).—If the string is perfectly flexible,  $N_t = n/2l \sqrt{F/\sigma} = n/2l \sqrt{F(1 + \alpha t)/\pi r_o^2 \rho_o}$ , if  $l$ , the distance between the bridges, is independent of  $t$ . Here  $n$  is the number of loops in the length  $l$ ,  $n$  may have any integral value, and  $\alpha$  is the coefficient of linear expansion of the string. Actual strings are not perfectly flexible; for them  $N = N_t(1 + c)$ , where  $c$ , the stiffness correction, increases as  $l$  is reduced. For a steel wire with  $r = 0.20$  mm,  $F$  constant and such that  $N = 76$  v.p.s. if  $l = 90$  cm, Melde (39) found  $c$  varied thus:

$l$ .....	90	45	30	22.5	18 cm
$c$ .....	0	1.3	1.8	3.9	5.3 %

2. *Ribbon Loud Speaker* (51).—When a variable electric current flows through a thin, corrugated, metallic ribbon mounted in a magnetic field, the ribbon vibrates, thus generating sound. For such loud speakers, an aluminum ribbon 10 cm long, 1 cm wide, 0.001 cm thick, weight = 30 mg, resistance = 0.05 ohm, is used; its maximum current, voltage, power, and amplitude are 10 ampere, 0.5 volt, 5 watt, and 0.5 cm. When fitted with a horn, the emitted speech was intelligible at a distance of 1 km (26).

3. *Longitudinal Vibration of a Stretched Wire* (12).— $N_t = 1/2l \sqrt{E/\rho}$  and is independent of  $F$ . For a steel wire of  $l = 676$  cm and  $r = \text{ca. } 0.2$  mm,  $N$  was found to be 762 v.p.s.

4. *Berger's Hydrophone* (50) consists of 3 steel strips, each 3.84 cm (1.5 in.) wide, 0.16 cm ( $1/16$  in.) thick, and about 180 cm (6 ft.)

long, attached, below the water-line, to the side of a ship, and set into longitudinal vibration by means of a friction drum driven by a 2.2 kw (3 h.p.) motor. The sound was heard under water to a distance of 6.4 km (4 miles).

5. *Tuning Forks* (3, 40).— $N = C \frac{a + \delta_a}{(l + \delta_l)^2} \sqrt{\frac{E}{\rho}}$ , where  $C$  is a numerical constant, and  $\delta_a, \delta_l$  are corrections which are independent of  $a$  and  $l$ . For steel forks,  $C \sqrt{E/\rho} = 81\,800$ ,  $\delta_a = 0.05$  cm,  $\delta_l = 0.38$  cm;  $l$  is the projection of the prong on the axis of the fork;  $N$  is independent of width perpendicular to plane of vibration. If  $-26^\circ\text{C} < t < +56^\circ\text{C}$ ,  $N_t = N_o/(1 + 0.000134t)$  (11); for higher temperatures, see Fig. 1. For variation of  $N$  with amplitude, see Fig. 2. By controlling the temperature and amplitude, and using a specially designed spark-gap, a fork of 25 v.p.s. has been vibrated several hours daily for several weeks without a change exceeding 1 in 10 000 in  $N$  (60). By means of a circuit containing an oscillating electron tube, forks of  $N = 50$  to 2000 v.p.s. may be kept in vibration without the use of a mechanical contact circuit breaker (16).

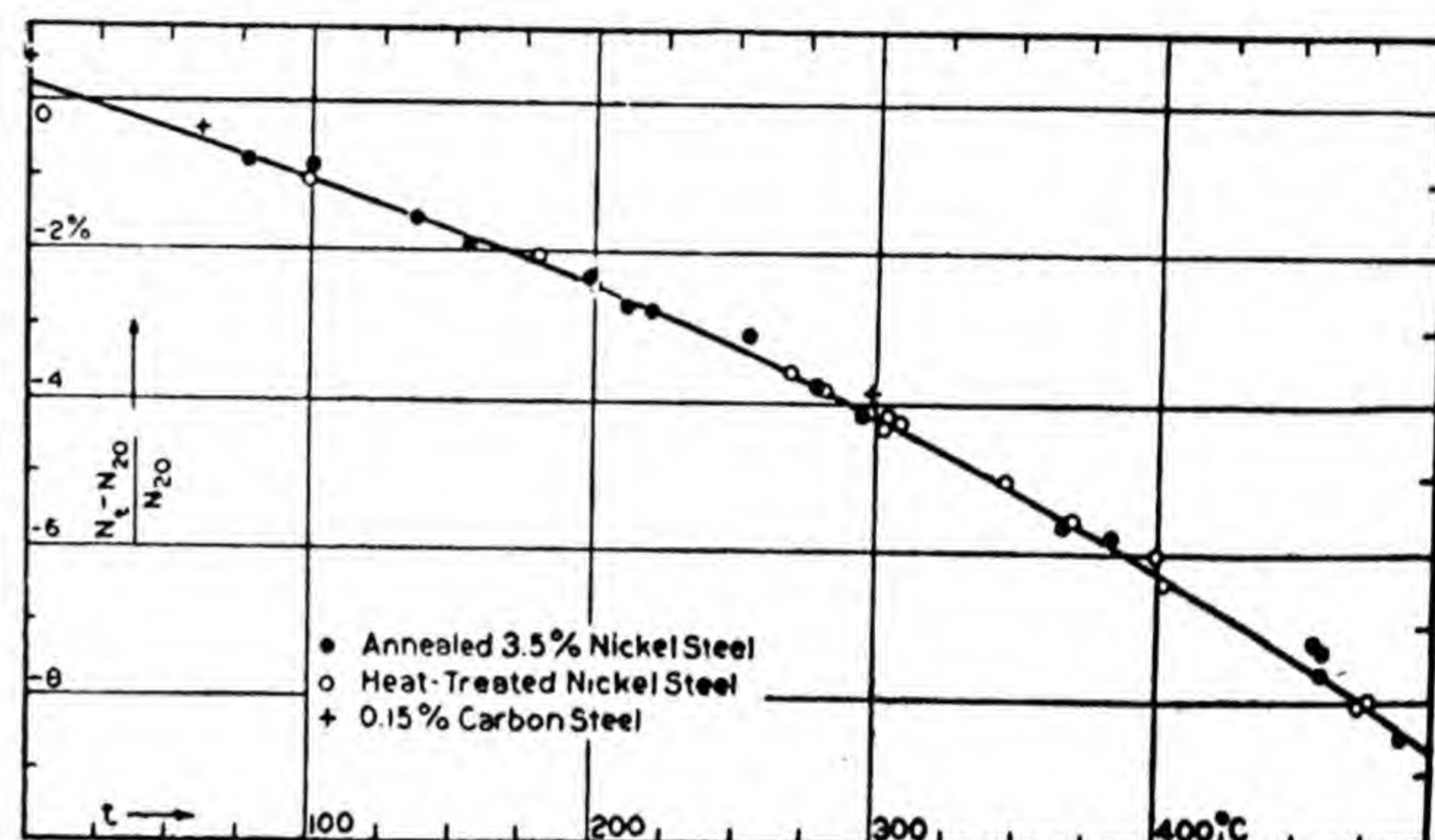


FIG. 1.—Tuning forks: Variation of frequency ( $N$ ) with temperature (31).

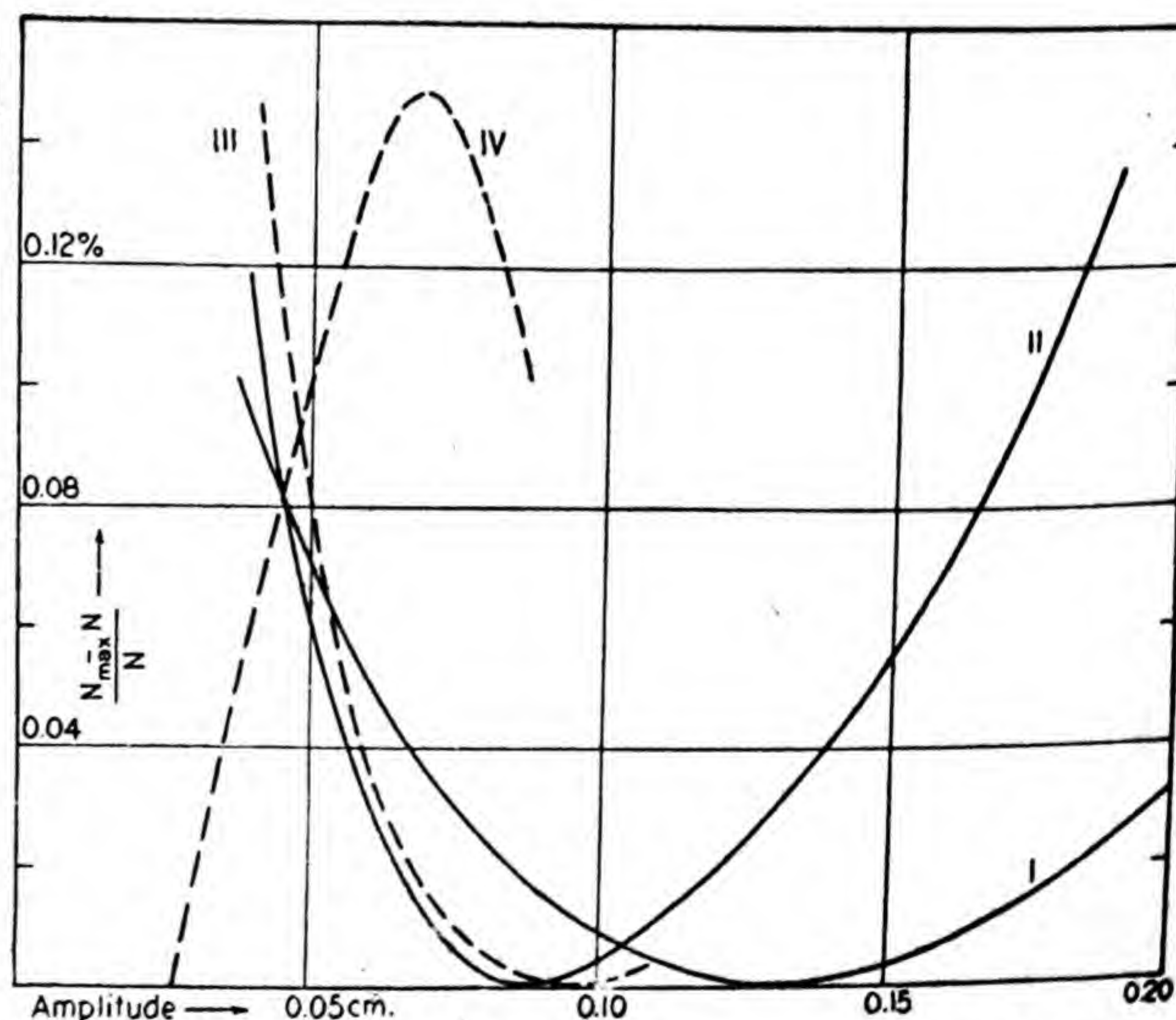


FIG. 2.—Tuning forks: Variation of frequency ( $N$ ) with amplitude (11). The driving current was interrupted by break between spring and point. Curves I and II refer to same fork; for I the amplitude was varied by varying the current, for II it was varied by changing the positions of the pole-pieces of the magnet. Curves III and IV refer to two other forks; the contacts of fork IV were mounted quite differently from those of the others.



6. *Telephone receivers* consist of a circular metallic diaphragm, either of magnetic material or with a plate of such material attached to its center, which is clamped along its circumference and is vibrated by a varying magnetic field. For variation of the amplitude with the frequency of the field, see Fig. 3. The over-all efficiency (Eff.) is defined as the ratio of the acoustic energy emitted to the electric energy supplied. For a bipole, 87 ohm, Bell telephone receiver,  $N = 992$  v.p.s., no cap over diaphragm,  $\text{Eff.} = (0.375 \pm 0.025)\%$  (33). For variation of Eff. with  $N$  see, Fig. 4. Minimum electrical power required to give a sound audible to a normal ear is of the order of  $3.3 \times 10^{-13}$  watt for a representative type of receiver (55). For acoustic characteristics, see (33).

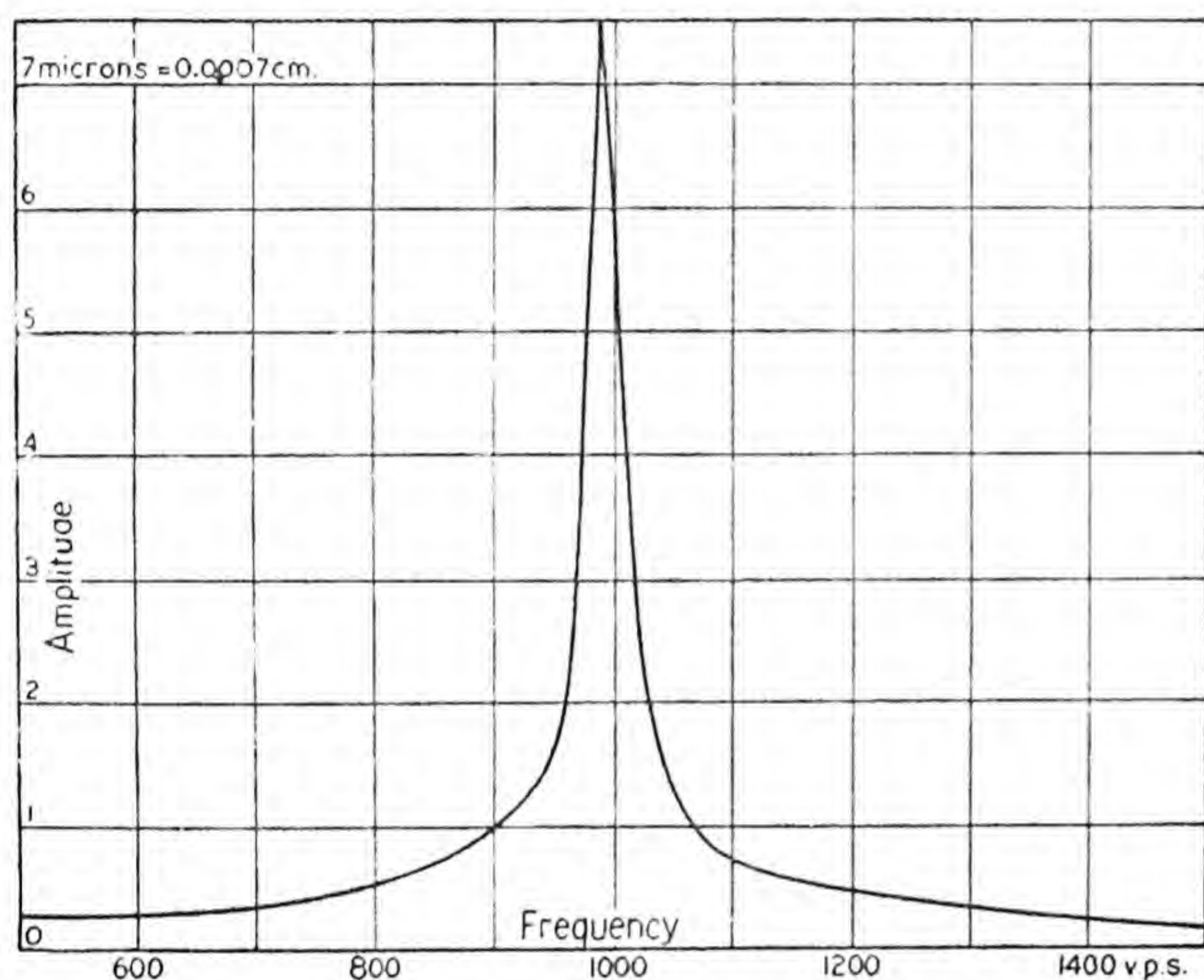


FIG. 3.—Telephone receiver: Variation of amplitude with frequency of current (30).

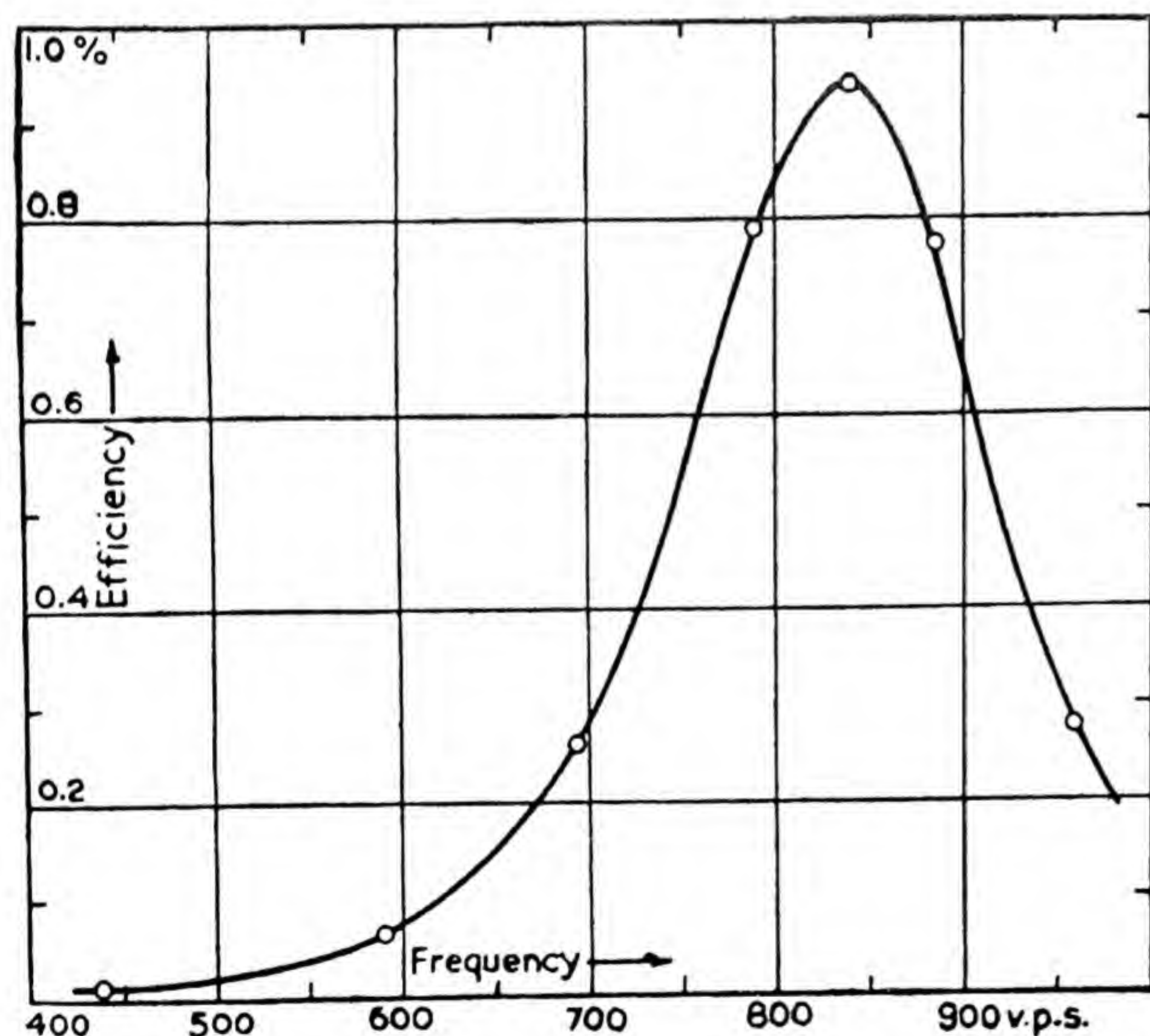


FIG. 4.—Telephone receiver: Variation of acoustic efficiency with frequency of the current (38).

Ordinates are the over-all efficiencies.

7. *Hewlett's tone generator* (27) consists of a thin, circular, metallic diaphragm clamped along its circumference, and placed between two flat circular coils, each wound in its own plane. By

a suitable bridge connection, a constant direct current is passed through the coils in such a way as to produce in the diaphragm a radial magnetic field, and at the same time, an alternating current is so passed through them as to produce an axial field. As a result, the diaphragm vibrates with the period of the alternating current. If the diaphragm is nonmagnetic and the current is simply harmonic, the tone is pure. When a certain instrument was excited by a direct current of 1.5 ampere and a voice current of 0.1 ampere, the reproduced speech was comfortably audible at all points in a room 20 ft. square (28). The amplitude ( $A$ ) varied thus with the frequency of the alternating current, the strength of the current remaining constant:

$N$ .....	1440	1600	2200	3700	v.p.s.
$A$ .....	4.6	4.16	4.04	1.72	$\times 10^{-6}$ cm

8. *Loud-speaker*.—For general discussion, see (13, 44); for "ribbon" loud-speaker, see 2, above. The over-all efficiency varies from 0.1% to 1% (13, 44). A balanced electromagnetic loud-speaker, diaphragm 7.62 cm (3 in.) in diameter, equipped with a horn, and radiating approximately 1 watt of acoustic energy, was heard loudly at a distance of 0.8 km (0.5 mile) (21). A loud-speaker equipped with a paper cone of  $45^\circ$ , maximum diameter = 15.25 cm (6 in.), paper 0.18 to 0.25 mm (0.007 to 0.010 in.) thick, had a general sensitivity equal to that of a good horn-type speaker, and responded to both low and high frequencies (48). Data for loud-speaker horns (19, 22).

9. *The Fessenden hydrophone oscillator* is a diaphragm operated by either an electrodynamic or electromagnetic drive. With the electrodynamic arrangement, a 5 kw. oscillator of 545 kg. wt. (1 200 lb. wt.) has a tuned diaphragm, about 60 cm (2 ft.) in diameter, clamped at the rim, and attached at the center to a light, hollow copper cylinder. This cylinder is mounted in a powerful magnetic field (about 15 000 line/cm<sup>2</sup>) so that alternating currents about the core inside the cylinder induce in the copper alternating currents of about 10 000 ampere. The cylinder is thus pushed and pulled with magnetic forces of about 1 800 kg. wt. (4 000 lb. wt.). When suspended 366 cm. (12 ft.) below the surface of open water the sound ( $N = 500$  v.p.s.) was detected under water at a distance of 57.4 km (1, 50).

10. *Electrostatic, or condenser, transmitter* (58) consists of an electric condenser composed of a thin (0.051 mm) metal diaphragm and a heavy plate separated by an air layer 0.025 mm thick. The diaphragm is under such radial tension that its natural frequency in air is 7000 v.p.s. An alternating voltage applied to the condenser causes the diaphragm to vibrate with twice the frequency of the voltage. The intensity of the emitted sound is of the same order as that from a telephone receiver. Such a transmitter may be used as a standard source of sound.

11. *Piston-phone* (56, 57).—A rotating cam imparts a simple harmonic motion to a piston which is attached to a diaphragm;  $N = 10$  to 200 v.p.s.

12, 13. *Piezoelectric Generator*.—A suitably cut, thin parallelepiped of a piezoelectric crystal (see p. 207) will execute dilatational-rarefactional vibrations when subjected to a transverse alternating electric field. The amplitude of the vibrations is exceedingly small unless the frequency of the field is near that of one of the natural periods of the parallelepiped. Such plates are useful for generating waves of high pitch.

If the plate is of quartz ( $\text{SiO}_2$ ) and is cut so that its broad faces are perpendicular to an electrical axis and its breadth is parallel to the optic axis, then its length ( $l$ ) will be perpendicular to each of these axes, and a varying field perpendicular to its broad faces will generate vibrations in the directions of  $l$  and of  $e$ , the thickness; the natural frequencies,  $N_l$  and  $N_e$  are given by the equations  $lN_l = eN_e = 275\,000$  cm v.p.s.



Plates of rochelle salt ( $\text{KNaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$ ) may be used likewise, and in some respects are superior to those of quartz (7).

14. *Bells* rung under water may be heard under water at a distance of 3 to 5 km (2 to 3 miles) (1, 41).

15. *Organ Pipes*.—The natural pitch of an open organ pipe is  $N = \frac{v}{2(l+c+c')}$ , and of a closed one is  $N = \frac{v}{4(l+c)}$ , where  $c$  = correction for mouth-end of pipe =  $2.7r$  (45),  $c'$  = correction for open end (if pipe has a flange  $c' = 0.82r$  (36), if no flange  $c' = 0.6r$  (45), observed value for thin brass tube of  $r = 5.3$  cm is  $c' = 0.576r$  (6)),  $v$  = velocity of sound in fluid filling the pipe =  $\sqrt{\gamma p/\rho} = v_0\sqrt{1+\alpha t+\beta t^2}$ ,  $\gamma$  = ratio of specific heats; for air,  $v_0 = 330.6$  m/sec,  $\alpha = 0.00371$ ,  $\beta = -0.126 \times 10^{-6}$ , for other fluids, see p. 461. The pitch of the sound actually emitted increases with the blowing pressure; for a pipe of natural pitch 255 v.p.s., the observed pitch was  $255 + \delta$ , where  $\delta$  varied as follows (46):

$p$ .....	1.9	2.08	2.2	2.69	3.35
$\delta$ .....	-0.5	+0.1	+1.5	+2.1	+4.2

$p$ .....	3.88	4.72	5.74	6.92	10.7 cm H <sub>2</sub> O
$\delta$ .....	+5.6	+7.1	+8.4	+9.3	+11 v.p.s.

The intensity ( $I$ ) also increases with the blowing pressure (37):

$p$ .....	20	24.8	30.8	35.8	39.0	cm H <sub>2</sub> O
$I$ .....	4	9	18	26	35	Arbitrary units

16. *Tonvariator* (53) is a Helmholtz resonator blown by air-blast. Its pitch can be varied continuously over about an octave; its tone is practically pure, the overtones being very high and weak (25, 47). The intensity ( $I$ ) increases linearly with the blowing pressure ( $p$  cm of H<sub>2</sub>O), at least within the range  $10 < p < 39.5$ , being given by  $I = 0.67p - 4.7$ , unit of  $I$  being arbitrary (37).

17. *Gallon's pipe* gives tones varying from about 3 500 to 50 000 v.p.s., depending upon its length ( $l$ ) and the width ( $w$ ) of its mouth (17):

$l$ .....	22.4	7.18	4.21	2.7	1.8
$w$ .....	2.3	1.6	0.9	0.9	0.9
$N/1000$ .....	3.48	10.0	15.0	20.0	25.0

$l$ .....	1.26	0.82	0.47	0.27 mm
$w$ .....	0.9	0.9	0.9	0.9 mm
$N/1000$ .....	30.0	35.0	40.0	45.0 v.p.s.

18. *Singing tube* (35) consists of an outer glass (pyrex) tube closed at one end, and a shorter inner tube open at both ends and at one end sealed to the outer tube at such a place that its other end is near the closed end of the outer tube. When the relative dimensions of the tubes are suitably adjusted, a strong, pure tone is emitted when the closed end of the tube is heated. The pitch depends upon the difference in temperature of the two ends of the tube. For a certain tube the following data were obtained (34):

$t_c$ .....	1	204	355	448	524	°C
$t_o$ .....	-181	-88	-16	+26	+57	°C
$t_c - t_o$ .....	182	292	371	422	+467	°C
$N$ .....	213	300	378	425	450	v.p.s.

19. *Thermophone* (2, 57).—When a very thin metallic strip immersed in a fluid is heated by an alternating electric current, the periodic expansion and contraction of the adjacent film of fluid give rise to vibrations in the fluid. The intensity of the sound is low, and is indefinite unless the fluid is confined in an enclosure of which the dimensions are all small as compared with the wavelength of the vibrations. If the heating current has a pure sine-wave form, the emitted sound is a pure tone of twice the frequency of the current. (See Fig. 5.)

20. *Siren*.—In a "pure tone" siren, the overtones are weak (42). (See Fig. 6.)

21. *Diaphone* (32) is a modified siren. It consists of a cylinder fitted with a piston which is oscillated through a small amplitude by compressed air, and which intermittently interrupts an air-blast. It emits a powerful tone. It may emit 1.76 kw (2.36 h.p.) of acoustic energy with an over-all efficiency of 6 to 8% and be heard for miles.

22. *Explosives* (23, 24, 52).—The detonation of bombs containing from 225 to 900 g (0.5 to 2 lb.) of T.N.T. (2, 4, 6-trinitrotoluene,  $\text{C}_7\text{H}_5\text{N}_3\text{O}_6$ ) has been used as an under-water source of sound. The sound from a 500 g bomb detonated at 8 to 10 m below the surface has been detected under water at distances of 15 to 18 km (52).

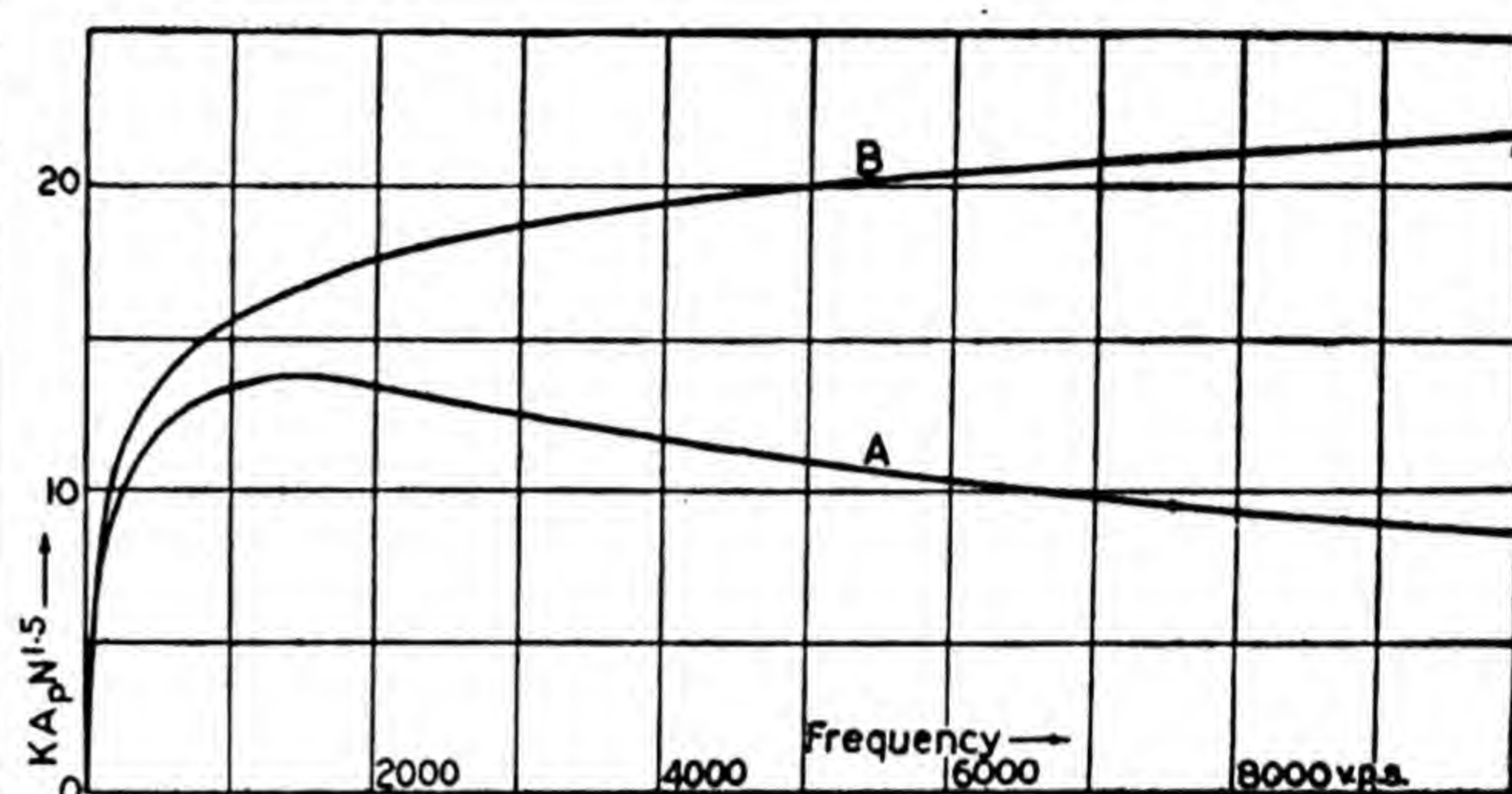


FIG. 5.—Thermophone: Relation between frequency ( $N$ ) and amplitude ( $A_p$ ) of oscillation of pressure (57).

In each case mean temperature of strip =  $335^\circ\text{K}$ , of air in enclosure =  $300^\circ\text{K}$ . For A, strip was a Wollaston wire 1 cm long,  $2r = 0.003$  mm; volume of enclosure =  $1\text{ cm}^3$ ; for B, strip was gold foil, area =  $5.5\text{ cm}^2$ , thickness =  $0.079\mu = 0.79 \times 10^{-5}$  cm; volume of enclosure =  $14\text{ cm}^3$ .  $K$  is a constant.

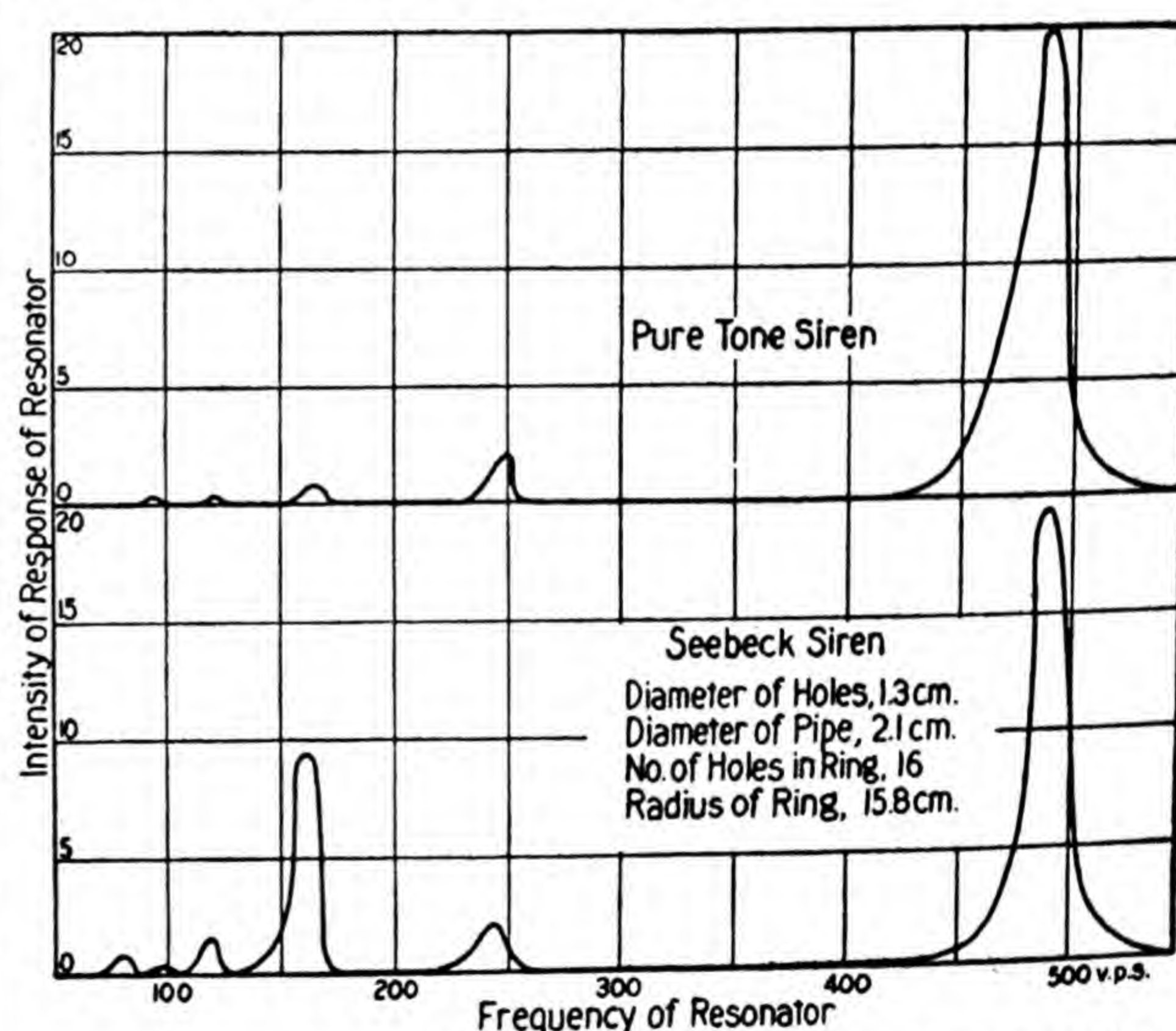


FIG. 6.—Sirens: Comparison of "Pure tone" and Seebeck sirens (42). Notes analyzed by means of resonators. Arbitrary unit of intensity.

#### DEVICES FOR STABILIZING THE FREQUENCY OF OSCILLATION OF CIRCUITS CONTAINING ELECTRON TUBES

The frequency of an oscillating electron tube and circuit may be stabilized by the use of a piezoelectric resonator (see No. 12 above). Variations with resonator are only about 3% of those without (8).

By the use of 2 electron tubes and coupling by tuned impedances, the frequency of oscillation of the circuit may be made quite independent of changes in plate voltage and in filament current.



In one case a change of 50 % in plate voltage produced but 0.1 %, and of 43 % in filament current produced but 0.3 %, change in the frequency (20).

By the use of a tuning fork (14, 29), the frequency can be maintained constant and equal to that defined by the fork to within 1 part in 100 000. Changing tubes produced a maximum effect of 1 in 100 000; there was no change as the tubes aged and no change as the filament current was reduced, provided the current was not less than 80 % of its normal value. As the plate voltage was increased the frequency increased by 0.0002 % per volt of change.

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## DETECTION AND MEASUREMENT OF SOUND

E. A. ECKHARDT

This bibliography covers all devices now available for quantitative measurements. For a recent discussion of such devices, see (39.1). Apparatus covering the range within which the human ear is sensitive (see p. 450) is very elaborate and compromises are generally required to meet a given situation.

1. Interferometric measurement of amplitude of changes in density (29, 35, 39).

2. Rayleigh disc: In free air (52); in simple resonator (12, 30); in double resonator (4, 38, 41).

3. Webster's phonometer (21, 42, 43).

4. Wien's vibration manometer (47, 51).

5. Torsion balance for measuring pondermotive force (2, 31, 51), theory (31).

6. Miller's phonodeik (23).

7. Ballistic phonometer (3).

8. Acoustic valves (28).

9. Magnetophones (20, 27, 34).

10. Contact microphones (10, 27).

11. Thermo-microphones (8, 9, 15, 16, 17, 24, 25, 33, 40).

12. Condenser microphones (5, 45, 46).

13. Resonators (13, 25, 26, 32, 40).

14. Horns (7, 11, 14, 18, 26, 36, 37, 43, 44).

15. Geophones (1, 22).

16. Hydrophones (6, 19, 48, 49, 50).

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TRANSMISSION, REFLECTION, REVERBERATION AND ABSORPTION OF SOUND

P. E. SABINE

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Symbols and definitions.	Symboles et définitions.	Symbole und Definitionen.	Simboli e definizioni.....	458
Transmission through tubes, horns and wave-filters.	Transmission à travers les tubes, trompes et filtres d'onde.	Transmission durch Röhren, Hörner und Wellenfilter.	Trasmissione attraverso tubi, trombe e filtri d'onda.....	458
Acoustic resistivity and transmission of plane waves from medium to medium.	Résistivité acoustique et transmission d'ondes planes de milieu à milieu.	Akustische Widerstandsfestigkeit und Transmission flacher Wellen von Medium zu Medium.	Resistività acustica e trasmissione delle onde piane da mezzo a mezzo.....	459
Transmission through septa bounded by air.	Transmission à travers les membranes entourées d'air.	Transmission durch Luftbegrenzten Septa.	Trasmissione attraverso setti circondati di aria...	459
Coefficient of acoustic absorption by boundaries.	Coefficient d'absorption acoustique par les parois.	Akustischer Absorptionskoeffizient an Grenzflächen.	Coefficiente di assorbimento acustico delle intercapedini.....	459
Absorbing power of objects.	Pouvoir absorbant des objets.	Absorptionsvermögen der Stoffe.	Potere assorbente di oggetti	460
Reverberation in rooms.	Réverbération dans les salles.	Widerhall in Räumen.	Riverberazione nelle stanze	460

SYMBOLS AND DEFINITIONS

<i>A</i>	Amplitude of displacement of element of the medium.
<i>a</i>	Absorbing power.
<i>E</i>	Bulk modulus, modulus of volume elasticity.
<i>I</i>	Intensity of the sound.
<i>l</i>	Length of a tube, or thickness of a septum.
<i>N</i>	Frequency, pitch, number of complete vibrations per unit of time.
<i>P</i>	Acoustic power.
<i>R</i>	Radius.
<i>s</i>	Area.
<i>T</i>	Duration of audible reverberation.
<i>t</i>	Time.
<i>V</i>	Volume of room or other enclosure.
<i>v</i>	Velocity of sound in medium considered.
v.p.s.	Vibrations per second.
<i>α</i>	Coefficient of absorption.
<i>δ</i>	Damping coefficient, coefficient of attenuation.
<i>λ</i>	Wave-length.
<i>μ</i>	Acoustic resistivity.
<i>ρ</i>	Density.
<i>σ</i>	Mass of septum per unit of area.

**Absorbing Power.**—As the result of the absorption of sound by a surface of area *s*, the intensity of the sound in an enclosure dies away exponentially after its emission ceases;  $I_t = I_0 e^{-\alpha s t / 4V}$ , where *t* is the time that has elapsed since *I* had the value *I*<sub>0</sub>, the source having ceased to emit sound prior to the beginning of the interval *t*, and *v* is the velocity of sound in the medium which fills the volume *V*. The absorbing power of the surface is *as*, and *α* is the coefficient of absorption. If the boundaries (walls, fittings, and occupants) consist of several types of surfaces, the total absorbing power is  $a = \alpha_1 s_1 + \alpha_2 s_2 + \dots$ ; it is of the dimensions of an area.

**Acoustic power** is the amount of acoustic energy that is emitted per unit of time.

**Acoustic resistivity** of a medium is  $\mu = \sqrt{E\rho}$ . It is the amount by which the r.m.s.<sup>1</sup> pressure in a plane wave must exceed the static pressure if the r.m.s.<sup>1</sup> velocity of the medium is to be unity.

**Coefficient of Absorption.**—See Absorbing power.

<sup>1</sup> r.m.s. = square root of the mean square.

**Coefficient of Attenuation.**—As a sound travels along a tube, the intensity decreases exponentially;  $I_x = I_0 e^{-\delta x}$ ; *δ* is coefficient of attenuation.

**Intensity (*I*)** of a sound is used in this section to denote the amount of acoustic energy per unit volume of the medium. For a single beam of advancing sound, *Iv* is the acoustic energy transmitted per unit of time through a unit of area perpendicular to the direction of propagation.

**Transmittivity** of an interface or septum = (transmitted energy) ÷ (incident energy).

**Reflectivity** of a surface = (reflected energy) ÷ (incident energy).

TABLE 1.—TRANSMISSION OF SOUND THROUGH TUBES, HORNS AND WAVE-FILTERS

Amplification by horns: theoretical (1, 2, 7, 8, 14, 17, 23, 37); experimental (3, 4, 12, 14, 15, 16, 18, 20, 21, 22, 31, 38, 39).

Wave-filters are conduits with side openings and, in certain types, associated branches and air-chambers; sounds in predetermined ranges of frequencies cannot pass through them. Theory and experiments (32).

For cylindrical tubes, radii *R*<sub>1</sub> and *R*<sub>2</sub> (*R*<sub>2</sub> = *r*<sub>2</sub>*R*<sub>1</sub>), connected by a cone of length *l*, sound proceeding from tube 1 to tube 2,  $\frac{A_2 R_2^2}{A_1 R_1^2} = \frac{1}{\left[1 + \frac{(r_2 - 1)^2}{r_2} \cdot \frac{(1 - \cos \eta)}{\eta^2}\right]^2 + \left[\frac{(r_2 - 1)^2}{r_2} \cdot \frac{(\eta - \sin \eta)}{\eta^2}\right]^2}$  where  $\eta = \frac{4\pi l}{\lambda}$  (5).

For tube of constant *R*,  $I_x = I_0 e^{-\delta x}$ ; tabular values are *δ* (11). Unit of *R* = 1 cm = 0.394 in.; of *l* = 1 m = 3.28 ft.; of *N* = 1 v.p.s.; of *δ* = 0.01 m<sup>-1</sup> = 0.00305 ft.<sup>-1</sup>.

2 <i>R</i>	<i>N</i> Material	254	1040	2285	3280	254	1040	2285	3250
		Straight tube				<i>l</i> = 3.04; 90° bend			
2.70	Brass.....	9.8		16.7	15.7				
2.70	Iron.....	12.1	13.4	18.7	20.0				
2.54	Fiber.....	14.8	15.1	25.2	30.2				
4.92	Brass.....	6.9	8.2	12.1	11.8	6.9	8.9	8.9	14.4
4.92	Fiber.....	8.9	13.5	14.1	15.1				
7.30	Brass.....	5.6	6.2	8.9	8.2	6.2	8.2	9.8	10.2
9.84	Brass.....		4.9	6.6	5.6	4.1	3.1	10.3	7.2



TABLE 2.—ACOUSTIC RESISTIVITY AND TRANSMISSION OF PLANE WAVES FROM MEDIUM TO MEDIUM (5)

The external media are assumed to have a thickness that is great as compared with  $\lambda$ ; the media are indicated by subscripts, 1, 2, 3, . . . , in the order in which they are entered by the wave,  $A_1, A_1r$  = displacement amplitude of incident, of reflected, wave in medium 1.

Two media, plane boundary, normal incidence.  $A_1 - A_1r = A_2$ ;  $(A_1 + A_1r)\mu_1 = A_2\mu_2$ ;  $(A_1 + A_1r)/(A_1 - A_1r) = \mu_2/\mu_1$ . Write  $m_2$  for  $\mu_2/\mu_1$ ; i.e.,  $\mu_2 = m_2\mu_1$ . Then for the interface, the transmittivity is  $A_2^2\mu_2/A_1^2\mu_1 = 4m_2/(m_2 + 1)^2$ ; the reflectivity is  $(m_2 - 1)^2/(m_2 + 1)^2$ .

Three media, plane parallel boundaries, normal incidence. Let  $m_2 = \mu_2/\mu_1$ ,  $m_3 = \mu_3/\mu_2$ , and  $l_2$  and  $\lambda_2$  = thickness of medium 2 and wave-length in it; then the transmittivity of the septum is

$$\frac{4m_2m_3}{(m_2m_3 + 1)^2} \left\{ 1 - \left[ \frac{(m_2^2 - 1)(m_3^2 - 1)}{(m_2m_3 + 1)^2} \sin^2 \frac{2\pi l_2}{\lambda_2} \right] \right\}$$

Acoustic resistivity ( $\mu$ ) =  $\sqrt{E\rho}$ ; velocity ( $v$ ) =  $\sqrt{E/\rho}$ . Unit of  $E$  = 1 kg wt./mm<sup>2</sup> = 1422 lb. wt./in.<sup>2</sup>; of  $\rho$  = 1 g/cm<sup>3</sup> = 62.4 lb./ft.<sup>3</sup>; of  $v$  = 1 m/sec = 3.28 ft./sec; of  $\mu$  = 10<sup>4</sup> g cm<sup>-2</sup> sec<sup>-1</sup> = 2.05 × 10<sup>4</sup> lb. ft.<sup>-2</sup> sec<sup>-1</sup>.

Medium	$E$	$\rho$	$v^*$	$\mu^*$
Steel.....	20 000	7.8	5 010	391
Cast iron.....	9 500	7.0	3 650	255
Brass.....	6 500	8.4	2 750	232
Bronze.....	3 200	8.8	1 890	166
Lead.....	600	11.4	718	81.9
Wood: Teak.....	1 600	0.86	4 270	37
Fir.....	900	0.45	4 430	20
Beech.....	600	0.80	2 710	22
Water.....	200	1.0	1 400	14
Rubber.....	<1	ca. 1	<100	<1
Air.....	0.014	0.0013	325	0.004

\* The numbers in this column have been slightly changed in order to make them accord with the tabulated values of  $E$  and  $\rho$ .

TABLE 3.—TRANSMISSION OF SOUND THROUGH SEPTA BOUNDED BY AIR

Quills.—Soft, flexible, porous, highly absorbent septa (25).  $\log_{10} (I_1/I_2) = \beta + \gamma l_2$ , where  $l_2$  = thickness of the septum and  $I_2$  is intensity after passage through the septum. Unit of  $\rho$  = 1 g/cm<sup>3</sup> = 62.4 lb./ft.<sup>3</sup>; of  $N$  = 1 v.p.s.; of  $\beta$  = 0.01; of  $\gamma$  = 0.01 cm<sup>-1</sup> = 0.305 ft.<sup>-1</sup>.

Material of septum	$\rho$	$N$ Covering	128		256		512		1024		2048		4096	
			$\beta$	$\gamma$	$\beta$	$\gamma$	$\beta$	$\gamma$	$\beta$	$\gamma$	$\beta$	$\gamma$	$\beta$	$\gamma$
Hair, loosely felted.....	0.14	None	38	5	25	8	35	10	35	15	26	17	48	17
Plant fiber board, coarse.....	0.24	None	77	25	77	20	68	29	105	41	10	70	22	80
Seaweed, quilted.....	0.11	Light paper	85	14	67	14	58	22	33	34	35	35	30	52
Plant fiber, soft, quilted.....	0.14	Heavy paper	71	17	56	14	45	23	45	55	50	108	100	123
Hair and asbestos fiber.....	0.40	Heavy paper	122	22	130	24	122	43	110	65				
Hair and asbestos fiber.....	0.55	Paper + burlap	60	36	96	34	87	63	56	100				

Wood, Glass, Steel (24).—Sound transmitted by forced vibrations of the septum: resonance may cause a large variation in transmission for a small variation in pitch. Tabulated values are averages for the 6 values of  $N$  of the preceding section. Each complete septum was 2.1 m by 0.79 m (= 6.9 ft. by 2.59 ft.);  $l$  = thickness of septum. Unit of  $l$  = 1 cm = 0.394 in.

Material	Remarks	$l$	$I_1/I_2$
Plate glass.....	1 pane	0.63	200
Plate glass.....	4 panes each, 38 by 99 cm	0.63	282
Plate glass.....	4 panes each, 38 by 99 cm	0.47	190
Plate glass.....	Small, leaded panes	0.47	302
Window glass.....	12 panes, each 25.4 by 48 cm	0.32	140
Steel door.....		0.63	1020
Wooden door.....	Panelled, birch veneer		74
Oak door.....	Solid, well seasoned	4.45	140
Oak door.....	Solid, damp	4.45	231

Masonry (27).—Tabulated values are averages for 20 tones covering the range  $N$  = 128 to 4096 v.p.s.; each septum was 1.88 m by 2.34 m (= 6.17 ft. by 7.68 ft.);  $I_1/I_2 = K\sigma^{2.5}$ , approximately, where  $K$  = 0.0112 m<sup>5</sup>kg<sup>-2.5</sup> = 0.590 ft.<sup>5</sup> lb.<sup>-2.5</sup>;  $l_i, l_p, l$  = thickness of tile, of plaster, of complete septum. Unit of  $l_i, l_p, l$  = 1 cm = 0.394 in.; of  $\sigma$  = 1 kg/m<sup>2</sup> = 0.205 lb. ft.<sup>2</sup>

Material	Remarks	$l_i$	$l_p$	$l$	$\sigma$	$I_1/I_2$	$K\sigma^{2.5}$
Gypsum tile.....	Solid	5.08		5.08	50.8	230	206
Gypsum tile.....	Hollow	7.62		7.62	54.3	260	243
Plaster.....	Solid, metal lath		3.81	3.81	68.0	340	427
Gypsum tile.....	Solid	7.62		7.62	69.5	468	451
Clay tile.....	Hollow	10.16		10.16	83.2	677	708
Gypsum tile.....	Solid, plastered	5.08	3.16	8.24	104.8	1180	1375
Gypsum tile.....	Solid, plastered	7.62	3.16	10.78	124.2	1910	1923
Clay tile.....	Hollow, plastered	10.16	3.16	13.32	141.0	2500	2640
Plaster.....	Solid, metal lath		8.9	8.9	159.0	4000	3570
Plaster.....	Solid, metal lath		11.75	11.75	204.0	6600	6660

TABLE 4.—COEFFICIENT OF ACOUSTIC ABSORPTION BY BOUNDARIES

If  $I_0$  is the intensity of sound in an enclosure, of volume  $\bar{V}$ , at some instant after the production of the sound has ceased, the intensity at a later time is  $I_t = I_0 e^{-at}/4\bar{V}$ , where  $a = \alpha_{1s_1} + \alpha_{2s_2} + \dots$ ;  $s_1$  = area of the boundary for which the coefficient of absorption is  $\alpha_1$ ;  $\alpha_{512}$  = value of  $\alpha$  for  $N$  = 512 v.p.s.;  $\alpha_{av}$  = average value of  $\alpha$  for range  $N$  = 128 to 4096 v.p.s. For data for special commercial sound-absorbent materials, see (36).

Masonry.— $l_m, l_c$  = thickness of material, of coating. Unit of  $l_m, l_c$  = 1 cm = 0.394 in.; of  $\alpha_{512}, \alpha_{av}$  = 0.01.

Finish	Material	$l_m$	$l_c$	$\alpha_{512}$	$\alpha_{av}$	Lit.
Unpainted.....	Brick	45		3.1	4.0	(26)
Painted.....	Brick	45		1.7	1.9	(26)
Smooth.....	Brick + gypsum plaster	45	1.5	1.2	1.5	(26)
Smooth.....	Clay tile + gypsum plaster	10		2.2	3.4	(26)
Smooth.....	Gypsum block + gypsum plaster	7.6		4.4	3.6	(26)
Smooth.....	Lime plaster, wood lath and studding			1.8	2.9	(26)
Smooth.....	Clay tile + gypsum plaster	10		2.0	2.8	(26)
Rough.....	Clay tile + gypsum plaster	10		4.9	4.4	(26)
Rough.....	Gypsum plaster, metal lath	6.3		4.7	3.6	(26)
Rough.....	Gypsum plaster, metal lath *	11.4		4.7	3.0	(26)
Rough.....	Lime plaster, wood lath and studding	11.4		3.4	3.0	(26)

\* Wood studding.

Furnishings and Wall Coverings.— $\alpha$  determined by method of reverberation, unless another is indicated; "draped" = draped back one-fourth;  $l$  = thickness of covering,  $\sigma$  = mass of covering per unit area. 1 cm = 0.394 in.; 1 g/m<sup>2</sup> = 0.00184 lb./yd.<sup>2</sup> = 0.000205 lb./ft.<sup>2</sup>; unit of  $\alpha$  = 0.01.

Material	Remarks	$\alpha_{512}$	Lit.
Audience.....	Closely seated	96	(26)
Cork.....	$l$ = 2.54 cm	12	(26)
Cork.....	$l$ = 3.8 cm	32*	(34)



TABLE 4.—(Continued)

Material	Remarks	$\alpha_{512}$	Lit.
Carpet.....	$l = 0.8$ cm	20	(26)
Carpet.....	Brussels	23*	(34)
Cheesecloth.....	$\sigma = 48$ g/m <sup>2</sup>	1.9	(26)
Chenille.....		23	(26)
Coco matting.....		17	(30)
Cotton draperies.....	Straight, $\sigma = 330$ g/m <sup>2</sup>	9	(29)
Cotton draperies.....	Draped, $\sigma = 330$ g/m <sup>2</sup>	29	(29)
Velour draperies.....	Straight, $\sigma = 580$ g/m <sup>2</sup>	10	(29)
Velour draperies.....	Draped, $\sigma = 580$ g/m <sup>2</sup>	37	(29)
Rugs.....	Oriental	29	(26)
Rugs.....	Oriental	26*	(34)
Linoleum.....		12	(26)
Felt.....	Asbestos, $l = 1.0$ cm	35	(26)
Felt.....	Asbestos, $l = 1.9$ cm	26*	(34)
Felt.....	Asbestos and hair	38	(26)
Felt, loose.....	Hair, $l = 2.54$ cm	52	(26)
Felt, loose.....	Hair, $l = 2.54$ cm	49	(29)
Felt, loose.....	Hair, $l = 2.54$ cm	51*	(34)
Felt, wood fiber.....	$l = 2.54$ cm, $\sigma = 1400$ g/m <sup>2</sup>	57	(29)
Fiber board.....	Sugar cane, $l = 1.1$ cm	20	(29)
Fiber board.....	Flax, $l = 1.43$ cm	28	(29)
Fiber board.....	Sugar cane, $l = 1.27$ cm	31	(35)
Fiber board.....	Wood, $l = 1.27$ cm	31	(35)
Glass.....		3	(26)
Wood sheathing.....	Pine, $l = 2$ cm	10	(26)
Cushions.....	$\alpha_{512}$ varies from 54 to 76	60	(26)

\* Flue method.

TABLE 5.—ABSORBING POWER OF OBJECTS

Absorbing power ( $a$ ) of an object =  $\alpha s$  (cf. Table 4). Unit of  $a = 0.01$  m<sup>2</sup> = 0.108 ft.<sup>2</sup>

Object	Remarks	$a$	Lit.
Audience.....	Per person	44	(26)
Chairs.....	Ash	1	(26)
Chairs.....	Wood, veneered	3	(29)
Church pews.....	Wood, per sitting	2	(35)
Pew cushions.....	Per sitting	13.5 to 19	(26)
Opera chairs.....	Seats upholstered	9 to 23	(35)
Opera chairs.....	Seats and backs upholstered	14 to 19	(29)

TABLE 6.—REVERBERATION IN ROOMS

Duration ( $T$ ) of audible reverberation in a room of volume  $V$  and absorbing power  $a$  is  $T = \frac{4V}{av} \log_e \frac{I_0}{i} = \frac{9.2V}{av} \log_{10} \frac{I_0}{i}$ , where  $I_0$  = average intensity of the sound at the instant its production ceased =  $\frac{4P}{av} (1 - e^{-avt/4V})$ , where  $t$  = the time the sound has been continuously produced;  $i$  = minimum audible intensity. Assume  $v = 342$  m sec<sup>-1</sup> (= 1122 ft. sec<sup>-1</sup>) and  $t$  is so great that  $I_0 = 4P/av$ , and put  $T_0$  = value of  $T$  when  $I_0/i = 10^6$ ;  $T_{10}$  = value of  $T$  when  $P/i = 10^{10}$  m<sup>2</sup> sec<sup>-1</sup> (=  $35.3 \times 10^{10}$  ft.<sup>2</sup> sec<sup>-1</sup>). Then if units are 1 m and 1 sec,  $T_0 = 0.161V/a$ ,  $T_{10} = 0.0269 \frac{V}{a} (8.07 - \log_{10} a)$ , and if units are 1 ft. and 1 sec,  $T_0 = 0.049 \frac{V}{a}$ , and  $T_{10} = 0.0082 \frac{V}{a} (9.10 - \log_{10} a)$ .

For each of the 11 rooms considered below,  $T$  is considered satisfactory for the purpose indicated. Values of  $T_0$  and  $T_{10}$  are computed from  $V$  and the known values of  $\alpha$  for the surfaces and furnishings, assuming  $N = 512$  v.p.s. and that the audience fills the room to its capacity. Key = key number of room. Unit of  $V = 1$  m<sup>3</sup> = 35.3 ft.<sup>3</sup>; of  $T_0$  and  $T_{10} = 1$  sec.

Key	Purpose	$V$	Seats	$T_0$	$T_{10}$	Lit.
1	Piano.....	74 to 210		0.95 to 1.10	1.07 to 1.19	(26)
2	Intimate drama....	1 700	300	1.20	1.14	(26)
3	Drama.....	5 900	1 670	1.51	1.23	(35)
4	Orchestra.....	11 500	1 600	2.35	2.02	(26)
5	Music, speech.....	12 200		1.70	1.41	(33)
6	Orchestra.....	18 400	2 600	2.33	1.92	(26)
7	Opera.....	14 200	2 350	1.51	1.23	(29)
8	Orchestra.....	20 600	2 300	2.40	1.96	(29)
9	Orchestra.....	22 400	3 340	2.08	1.66	(35)
10	Orchestra, speech...	22 600	5 000	1.70	1.33	(33)
11	Music, speech.....	26 200	3 640	1.90	1.48	(29)

KEY NUMBERS AND LOCATIONS OF ROOMS STUDIED

Key	Name and location
1	New England Conservatory, Boston (5 small rooms)
2	Little Theater, New York, N. Y.
3	Apollo Theater, Chicago, Ill.
4	Gewandthaus, Leipzig, Germany
5	Academy of Music Opera House, Brooklyn, N. Y.
6	Symphony Hall, Boston, Mass.
7	Opera House, Boston, Mass.
8	Masonic Auditorium, Cleveland, Ohio
9	Eastman Theater, Rochester, N. Y.
10	Hill Memorial, Ann Arbor, Mich.
11	Auditorium Theater, Chicago, Ill.

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(For a key to the periodicals see end of volume)

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## VELOCITY OF SOUND

ARTHUR L. FOLEY

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE
Symbols.	Symboles.	Zeichen.	Simboli.	461
Relation of velocity to various factors.	Relations entre la vitesse et divers facteurs.	Beziehung der Geschwindigkeit zu verschiedenen Faktoren.	Rapporto della velocità con altri fattori.	461
Velocity of sound in:	Vitesse du son dans:	Geschwindigkeit des Schalles in:	Velocità di propagazione del suono in:	
Free air.	L'air libre.	Freier Luft.	Aria libera.	461
Gases and vapors:	Les gaz et vapeurs:	Gasen und Dämpfen:	Gas e vapori:	
One temperature.	À une température.	Bei bestimmter Temperatur.	A una data temperatura.	462
Variation with temperature.	Variation avec la température.	Änderung mit der Temperatur.	Variazione con la temperatura.	463
Liquids.	Les liquides.	Flüssigkeiten.	Liquidi.	464
Natural waters.	Les eaux naturelles.	Natürlichen Wässern.	Acque naturali.	464
Solids.	Les solides.	Festen Stoffen.	Solidi.	465
Velocity of sound in gases confined in tubes.	Vitesse du son dans les gaz confinés dans des tubes.	Geschwindigkeit des Schalles in Gasen innerhalb von Röhren.	Velocità di propagazione del suono nei gas racchiusi in tubi.	466

As the determination of the velocity of sound is beset by many difficulties, the values obtained by different observers under nominally identical conditions are frequently quite different. Hence, it has seemed best to give either the individual observations, if few, or the simple average of all, if many (occasionally excluding a few that are markedly discordant); and, when data corresponding to each of a series of values of a single variable are available, to give, if possible, the coefficients of a simple empirical equation that represents the series within the estimated experimental error. Such an equation should not be used beyond the indicated limits. The averages and coefficients have been determined for these tables; the literature references indicate merely the sources of the data upon which they rest. Wherever given, the deviations from the equations refer to the deviations of the values derived by the authors, not necessarily of the individual determinations.

## SYMBOLS

$t$	Temperature, °C.
$T, T_0$	Absolute temperature, absolute temperature of 0°C.
$V$	Velocity of sound in an unlimited volume of the medium, except in Table 7 where it is the observed velocity in the confined gas. Subscripts (e.g., $V_t$ ) indicate the temperature, or the temperature and pressure, to which $V$ refers.

## RELATION OF VELOCITY OF SOUND TO VARIOUS FACTORS

**Pitch.**—For frequencies up to 800 000 per sec, the velocity in free air and in free illuminating gas has been found to be independent of the pitch (22, 58). For air and CO<sub>2</sub>, see (71). When a gas is confined in a tube, the velocity is less than in the free gas, but approaches that as the frequency is increased; see Table 7. In liquids also, the velocity is independent of the pitch unless the viscosity is very great and the frequency is very high; in going from 43 000 to 600 000 per sec, the velocity in water decreases only 5% (8). In glass rods, the velocity of transverse waves increases with the frequency and with the diameter; an increase from 400 m/sec to 2 400 m/sec has been observed when the frequency was increased from 285 000 to 455 000 per sec (111).

**Intensity.**—Even at ordinary intensities, the velocity is only approximately independent of the intensity, and at great intensities it is far from such independence, the velocity increasing with the intensity (9, 28, 32, 50, 61, 62, 72, 73, 83, 96, 97, 100, 102, 109). The effect of the motion of the medium (*q.v.*) must be considered.

Velocities ranging from 331 to 1270 m/sec in air (32, 72, 100), and from 1400 to 2013 m/sec in water (96) have been observed.

**Medium.**—Unless the intensity is great, the velocity of sound with reference to the medium is quite approximately given by the equation  $V^2 = E/d$ , where  $E$  is the adiabatic volume elasticity, and  $d$  is the density of the medium. In general, both  $E$  and  $d$  vary with the temperature, pressure, and composition of the medium. For an ideal gas,  $E = \gamma p$ , and  $V_t = V_0 T/T_0$  is independent of the pressure;  $\gamma$  = ratio of the specific heats. For many actual gases an equation of the form  $V_{t,p}^2 = V_{0,p}^2(1 + at + bt^2)$  represents the observations within their experimental error;  $a$  will usually differ from  $1/T_0$ . Irons (47) concludes that the best general equation is  $V = a + bT^n$ , where  $n$  is near 0.5 and varies with the complexity of the molecule.

**Velocity of Medium.**—When the medium is streaming with reference to the observer, the apparent velocity of the sound is the sum of the normal velocity and that component of the mass velocity of the medium which is in the direction of the line joining the source and the observer. The wave-front of the sound wave from a gun is a circle with a moving center (67); if the distance measured along the axis of the gun from the muzzle to the wave-front is  $x$ , then  $x = V\tau + a(1 - e^{-b\tau})$ , where  $V$  is the normal velocity, and  $\tau$  is the time since the initiation of the wave. The apparent velocity is  $dx/d\tau = V + abe^{-b\tau}$ . For a 10-inch gun firing a service charge,  $a = 22$  m, and  $b = 27 \text{ sec}^{-1}$  (67); see also (48).

**Velocity of Source.**—Giving the source a velocity of 85.5 m/sec with reference to the medium and observer, relatively at rest, produces no change in the velocity of the sound (1).

**Radiation.**—Under the action of X-rays an increase of 5% in the velocity in O<sub>2</sub> and N<sub>2</sub>, and a greater increase in H<sub>2</sub> have been observed (55). The action of ultra-violet light on O<sub>2</sub> forms ozone and decreases the velocity. Radiation from Ra produces no change. Velocity in argon is unaffected by radiation (92). It has been suggested that the effect upon the velocity arises, in general, from a change in the ratio of the specific heats (20).

**Topography.**—The apparent velocity in free air is affected by the local topography and altitude (10, 59, 85).

TABLE 1.—VELOCITY OF SOUND IN FREE AIR

The following data refer to dry air. The presence of water vapor increases the velocity. If  $e$  = pressure of water vapor present in air at barometric pressure  $p$ , then

$$V_d = V_a \sqrt{1 - \frac{e}{p} \left( \frac{\gamma_w}{\gamma_a} - \frac{5}{8} \right)},$$



where  $V_d$  and  $V_h$  = velocity in dry and in humid air of the same temperature, and  $\gamma_a$  and  $\gamma_w$  = ratio of specific heats of air and of water (88). Observed values (59) of  $V_h$  at 75 % of saturation and over range  $-14$  to  $+27^\circ\text{C}$  are significantly greater than those computed by means of this equation, the value at  $21.85^\circ$  being  $353.0$  m/sec while the values computed for 50 % and 100 % are only  $345.5$  and  $346.2$ ,  $V_d$  being taken as  $344.7$ , which corresponds to  $V_0 = 331.7$ . Unit of  $V = 1$  m/sec; of  $p = 1$  atm.; temperature =  $t$ ,  $^\circ\text{C}$ .

#### Velocity ( $V_0$ ) at $0^\circ\text{C}$ , and 1 Atm.

It has been noticed (33) that, from 1738 to 1919, there seems to be a progressive decrease, totaling about 0.3 %, in the recorded values of  $V_0$ , suggesting a slight change in the constitution of the atmosphere. This decrease has not been considered in taking the following averages. In the table are given (a) the unweighted averages of the recorded values grouped roughly according to method used; (b) the weighted average of all values obtained prior to 1902 (74); and (c) the average of the 1902 average and the best values obtained since then (33).

Method	Range	$V_0$	Lit.
Gun fire.....	330.7-332.4	331.4	(2, 3, 10, 12, 30, 34, 67, 68, 72, 90)
Pipes and tubes.....	330.0-331.9*	331.1	(6, 22, 23, 26, 57, 72, 80, 88, 101, 102, 105)
Other methods.....	331.3-332.1	331.6	(39, 40, 59, 94, 95)
Weighted mean prior to 1902.....		331.78	(74)
Weighted mean to 1927.....		331.45	(33)

\* Omitting 328.6 (23).

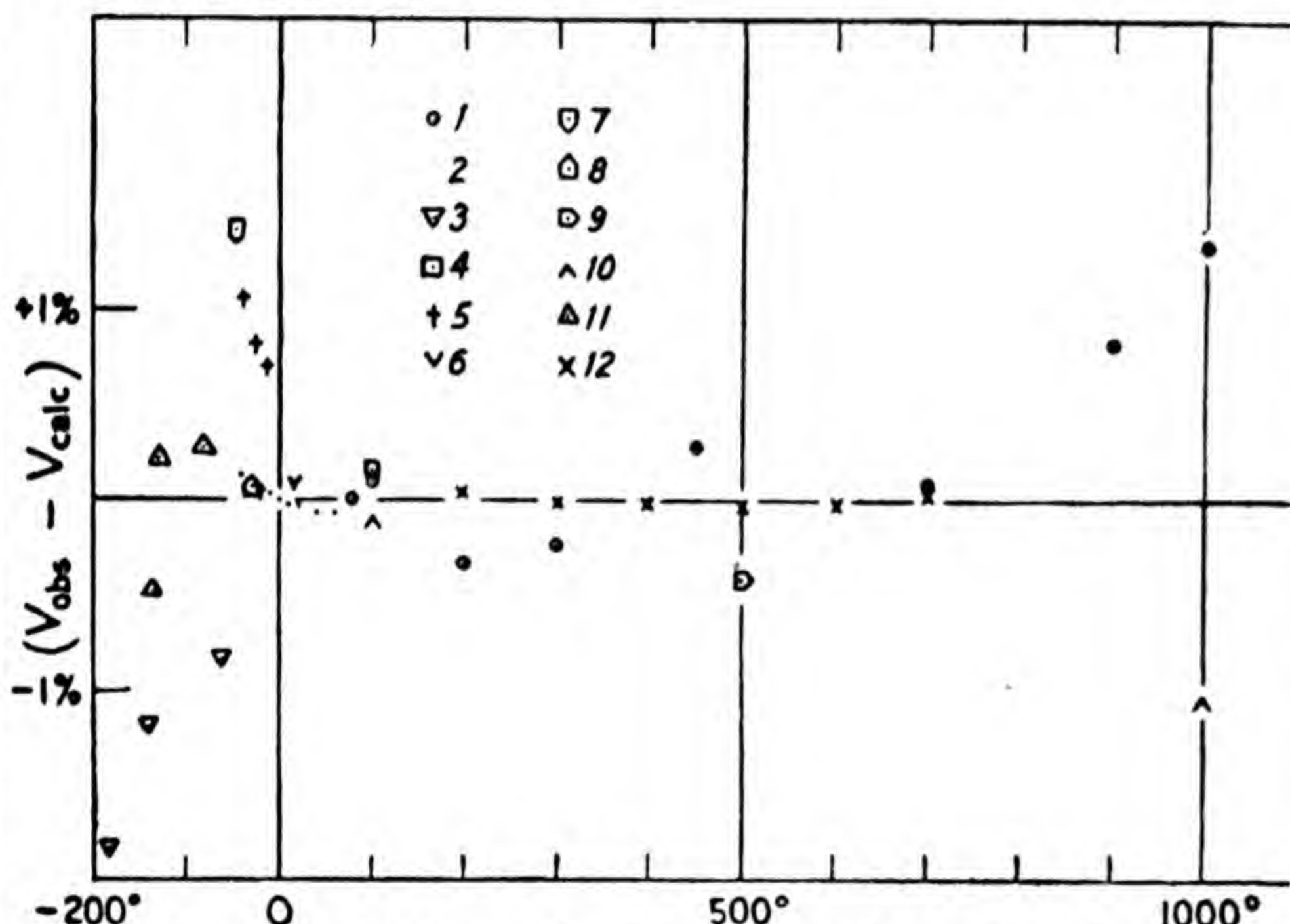


FIG. 1.—Excess of observed velocity in air above that calculated by means of the equation

$$V_t = 330.6 \sqrt{1 + 0.003707t - 1.256t^2 \times 10^{-7}}$$

1. Average of several observers.
2. Ciccone and Campanile (17).
3. Cook, and Witkowski and Cook (19, 107), values at  $-136^\circ$  and  $-104^\circ$ , 3.55 % and 3.42 % low, lie below the bottom of the figures.
4. Dixon, Campbell, and Parker (23).
5. Dulong (26).
6. Esclancon (30).
7. Greeley (38).
8. Grüneisen and Merkel (39).
9. Low (58).
10. Stevens (88).
11. Strecker (91).
12. Zoch (113).

#### Variation of $V_t$ with Temperature

The recorded values between  $-181$  and  $+1000^\circ$  are represented by the equation  $V_t = 330.6 \sqrt{1 + 0.003707t - 1.256t^2 \times 10^{-7} \times (1 + \delta)}$ , where  $\delta$  has the values shown in Fig. 1; with two exceptions, the extreme range of  $\delta$  is from  $-1.83$  % at  $-181^\circ$  to  $+1.42$  %

at  $-45.6^\circ$ , and between 0 and  $700^\circ$  the range is from  $-0.43$  to  $+0.29$  %.

#### Variation of $V_t$ with Pressure (52, 107); cf. (53, 89)

$\Delta \equiv (V_p - V_1) \div V_1$ , temperature constant. Unit of  $p = 1$  atm.; of  $\Delta = 0.01$

$t$	$-140^\circ$	$-103.5^\circ$	$-79.3^\circ$	$-78.5^\circ$	$-35^\circ$	$0^\circ\text{C}$	Lit.
$p$							
20	-16.8	-3.1		-1.8	-0.3	-0.1	(107)
25			-1.7			+0.8	(52)
40		-5.8		-3.2	-0.3	+0.5	(107)
50			-1.8			+2.2	(52)
60				-2.5	0	+1.8	(107)
75			-0.2			+4.1	(52)
80					+1.3	+3.5	(107)
100						+6.0	(107)
100		+12.8				+6.4	(52)
125		+22.7				+9.5	(52)
150		+33.4				+13.2	(52)
175		+45.4				+17.3	(52)
200		+56.4				+19.0	(52)

TABLE 2.—VELOCITY OF SOUND IN GASES AND VAPORS: ONE TEMPERATURE

(For variation with temperature, see Table 3.) Temperature =  $t$ ,  $^\circ\text{C}$ ; pressure = 1 atm.;  $\Delta_a$  = average departure of observed velocities from the value tabulated; if no value given for  $\Delta_a$ , there is but one acceptable determination. The symbols serve merely to identify the gases, and give no indication of their molecular states. Unit of  $V = 1$  m/sec; of  $\Delta_a = 1$  % of  $V$ .

Gas	$t$	$V_t$	$\Delta_a$	Lit.
Air.....	See Table 1			
A.....	0	307.8	0.2	(23, 45)
Br.....	0	135.0		(91)
Ca.....	850	652		(104)
Cl.....	0	205.8	0.2	(64, 91)
H.....	0	1261.7*	0.3	(21, 26, 39, 72, 75, 93)
He.....	0	971		(75)
Hg.....	330	187.0†		(54)
I.....	0	107.7†		(91)
K.....	850	652		(104)
N.....	0	337.7	0.1	(11, 23, 75, 79, 80)
O.....	0	316.2	0.3	(26, 75)
H <sub>2</sub> O.....	0	401		(65)
HCl.....	0	295.2	0.4	(65, 80, 91)
HBr.....	0	199.8		(91)
HI.....	0	157.1		(91)
ICl.....	0	135.4		(91)
IBr.....	0	120.4		(91)
SO <sub>2</sub> .....	0	209.2	0.1	(65, 80)
H <sub>2</sub> S.....	0	289.3		(65)
NO.....	0	325		(65)
N <sub>2</sub> O.....	0	260.5	1.3	(45, 64, 72, 80, 112)
NH <sub>3</sub> .....	0	414.8	0.2	(65, 80, 112)
CO.....	0	337.4	0.1	(80, 112)
CO <sub>2</sub> .....	0	259.3‡	0.6	(11, 23, 26, 45, 64, 65, 80, 112)
SiF <sub>4</sub> .....	0	167.4		(65)

\* Values 1238 (58), 1226 (80), and 1286.0 (113) have been ignored

† At pressure of saturated vapor.

‡ Zoch (113) finds 281.9.

Formula	Name	$t$	$V_t$	$\Delta_a$	Lit.
CCl <sub>4</sub>	Carbon tetrachloride.....	77	150.2		(56)
CS <sub>2</sub>	Carbon disulfide.....	0	195.0		(5)
CHCl <sub>3</sub>	Chloroform.....	20	155		(5)
CH <sub>2</sub> Cl <sub>2</sub>	Methylene chloride.....	43	175.9		(36)



TABLE 2.—(Continued)

Formula	Name	<i>t</i>	<i>V<sub>t</sub></i>	$\Delta_a$	Lit.
CH <sub>4</sub>	Methane.....	0	430.5	0.3	(23, 65)
CH <sub>3</sub> O	Methyl alcohol.....	67	341.2		(56)
C <sub>2</sub> N <sub>2</sub>	Cyanogen.....	0	229.5		(65)
C <sub>2</sub> H <sub>2</sub>	Acetylene.....	0	327.5	0.2	(45, 80)
C <sub>2</sub> H <sub>4</sub>	Ethylene.....	0	317.0	0.5	(26, 45, 65, 80, 112)
C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Acetic acid.....	136	209		(88)
C <sub>2</sub> H <sub>6</sub>	Ethane.....	0	303.0*		
C <sub>2</sub> H <sub>6</sub> O	Ethyl alcohol.....	0	230.6		(65)
C <sub>3</sub> H <sub>6</sub> O	Allyl alcohol.....	95	218.5		(36)
C <sub>3</sub> H <sub>6</sub> O	Propionaldehyde.....	50	258.3		(36)
C <sub>3</sub> H <sub>6</sub> O	Acetone.....	58	208.4		(36)
C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	Propionic acid.....	146	232		(56)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Butyric acid.....	158	222.2		(56)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Isobutyric acid.....	150	208.4		(56)
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Ethyl acetate.....	76	208.1		(56)
C <sub>4</sub> H <sub>10</sub> O	Ethyl ether.....	0	180.6	0.8	(5, 65)
C <sub>4</sub> H <sub>10</sub> O	Butyl alcohol.....	82	225.6		(56)
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Valeric acid.....	169	218.4		(56)

TABLE 2.—(Continued)

Formula	Name	<i>t</i>	<i>V<sub>t</sub></i>	$\Delta_a$	Lit.
C <sub>5</sub> H <sub>12</sub>	Pentane.....	43	191.5		(24)
C <sub>5</sub> H <sub>12</sub> O	Amyl alcohol.....	136	218.8		(56)
C <sub>6</sub> H <sub>6</sub>	Benzene.....	15	193		(5)
C <sub>6</sub> H <sub>14</sub>	Hexane.....	80	184.2		(24)
C <sub>8</sub> H <sub>16</sub> O <sub>2</sub>	Isobutyl butyrate.....	157	184.3		(56)
C <sub>10</sub> H <sub>20</sub> O <sub>2</sub>	Isomyl valerate.....	166	157.2		(56)
	Benzine.....	90	200		(24)
	Coal gas.....	0	500†		(58, 113)
	Coal gas.....	13.6	453		(22)
	Gasoline.....	50	171.3		(36)

Mixed Gases (24), 20°C; volume %.

% H <sub>2</sub>	% O <sub>2</sub>	<i>V</i>	% H <sub>2</sub>	% CO <sub>2</sub>	% Air	<i>V</i>	% N <sub>2</sub>	% CO	<i>V</i>
56.4	43.6	474.2	61.2	38.8		424.8	83.8	16.2	351.8
51.6	48.4	453.5	34.1	65.9*		328.5	39.4	60.6	351.6
21.0	79.0	364.7	51.2	43.5	5.3	389.2			

\* Deduced from observations at various temperatures; cf. Table 3. Heuse (48) gives  $V_0 = 378$ . † Low (58) finds 490 to 515; Zoch (113) gives 490.4.

TABLE 3.—VELOCITY OF SOUND IN GASES AND VAPORS: VARIATION WITH TEMPERATURE

The empirical equation  $V = V' \sqrt{1 + \alpha t 10^{-3} + \beta t^2 10^{-6}}$  should not be used beyond the "range" indicated; when  $\beta$  is not zero, its value is given in a foot-note.  $\Delta_a$  = average departure of the submitted data from the value given by the empirical formula. The pressure is not always explicitly stated by the observer; it is assumed to be 1 atm. unless another value is indicated. Unit of  $V' = 1$  m/sec; of  $\Delta_a = 1\%$   $V'$ . Temperature =  $t$ , °C.

Symbol	Substance	<i>V'</i>	$\alpha$	Range	$\Delta_a$	Lit.
	Air, v. Table 1.....					
A	Argon.....	307.8	3.677	0° to 1000°	0.1	(23, 45)
Hg	Mercury*.....	$V_{330} = 187.0$ ; $V_{360} = 208.1$				(54, 56)
I	Iodine*.....	107.7	3.937	0° to 290°	0.9	(56, 88, 91)
N	Nitrogen.....	337.7	3.586	0° to 1000°	0.1	(11, 23, 75, 79, 80)
O	Oxygen.....	316.2	3.781	-184.7° to 21°	†	(19, 26, 75)
	Oxygen.....	300.8	3.652	-184.7° to -28.4°	1.0	(19)
H <sub>2</sub> O	Water.....	$V_0 = 401$ ; $V_{93} = 402$ ; $V_{96} = 410$				(49, 65)
	Water.....	$V_{110} = 413$ ; * $V_{120} = 417.5$ ; * $V_{130} = 424.4$ *				(98)
	Water.....	$V_{100} = 471.5$ ; $V_{1000} = 853.9$				(82)
NH <sub>3</sub>	Ammonia.....	414.8	3.716	0° to 86°	0.1†	(24, 65, 80, 112)
N <sub>2</sub> O	Nitrous oxide.....	$V_{14.5} = 264.6$ ; $V_{600} = 446.9$				(82)
CO <sub>2</sub>	Carbon dioxide.....	258.0	3.630	0° to 1080°	0.0†	(11)
	Carbon dioxide.....	258.4	3.534§	0° to 600°	0.0	(23)
	Carbon dioxide.....	$V_{15} = 264.7$ ; $V_{1000} = 523.4$				(82)
CS <sub>2</sub>	Carbon disulfide.....	195.0	2.126	0° to 70°	0†	(5, 56)
CHCl <sub>3</sub>	Chloroform.....	$V_{20} = 155$ ; $V_{63} = 144.5$ ; $V_{80} = 163$ ; $V_{99.8} = 171.4$				(5, 36, 88)
CH <sub>4</sub>	Methane.....	430.5	2.857	0° to 600°	0.2	(23, 65)
CH <sub>3</sub> O	Methyl alcohol.....	$V_{67} = 341.2$ ; $V_{77} = 325.7$ ; $V_{99.7} = 350.3$ *				(24, 56, 88)
C <sub>2</sub> H <sub>4</sub>	Ethylene.....	317.0	3.142§	0° to 89°	0.1	(24, 26, 45, 65, 80, 112)
C <sub>2</sub> H <sub>6</sub>	Ethane.....	303.0	3.304	10° to 100°	0.1†	(23)
C <sub>2</sub> H <sub>6</sub> O	Ethyl alcohol.....	230.6	4.10	0° to 99.8	1.1†	(24, 56, 65, 70, 88)
C <sub>4</sub> H <sub>10</sub> O	Ethyl ether.....	180.6	1.250§	0° to 100	0.4†	(5, 24, 49, 65, 93)
C <sub>4</sub> H <sub>10</sub> O	Butyl alcohol.....	$V_{82} = 225.6$ ; $V_{116} = 235.4$				(56)
C <sub>5</sub> H <sub>12</sub>	Pentane.....	163.9	10.16§	43° to 86°	0.1	(24)
C <sub>6</sub> H <sub>6</sub>	Benzene.....	$V_{15} = 193$ ; $V_{90} = 200$ ; $V_{100} = 205$				(5, 24, 88)

\* At pressure of saturated vapor.

† For 0°, 21°, and -184.7°,  $\Delta_a = 0.2$ ; at -28.4°, -66.5°, and -137.3° computed  $V$  too great by 5.5 %, 3.4 %, and 4.1 %, respectively.

‡ The following values have been omitted: NH<sub>3</sub>,  $V_0 = 407.4$  (72), low 1.8 %. CO<sub>2</sub>,  $V_{20} = 257.3$  (58), = 259.8 (93), low 3.7 % and 2.7 %. CS<sub>2</sub>,  $V_0 = 189$  (68),  $V_{15} = 187.7$  (36), low 3.1 % and 8.3 %. C<sub>2</sub>H<sub>6</sub>,  $V_0 = 378$  (45), high 25 %. C<sub>2</sub>H<sub>6</sub>O,  $V_{48} = 235.7$  (49), low 6.6 %. C<sub>4</sub>H<sub>10</sub>O (ether),  $V_{17} = 175.9$  (88) and  $V_{15} = 180.0$  (36), low 4.0 % and 3.8 %;  $V_{16} = 192.8$  (58) and  $V_{17} = 194.4$  (70), high 2.8 % and 3.5 %.

§ Values of  $\beta$ : CO<sub>2</sub>, -0.210; C<sub>2</sub>H<sub>4</sub>, 24.6; C<sub>4</sub>H<sub>10</sub>O (ether), 25.0; C<sub>5</sub>H<sub>12</sub>, -37.6.||  $V_{99.7} = 223.2$  (88), high 4.4 %; at pressure of saturated vapor.



TABLE 4.—VELOCITY (V) OF SOUND IN LIQUIDS

Pure liquids; aqueous solutions; ill-defined liquids. In column C is given either the density (g/cm<sup>3</sup>) or the wt. % of the solute; temperature = *t*, °C. Unit of *V* = 1 m/sec.

Pure Liquids					
Symbol	Substance	<i>t</i>	<i>V<sub>t</sub></i>	Lit.	
Hg	Mercury.....	20	1407	(13)	
H <sub>2</sub> O	Water, distilled, air-free.....	15	1447*	(25)	
		4	1419.2	(13)	
		21.5	1483.6	(13)	
		15	1433†	(64)	
HNO <sub>3</sub>	Water, pure.....	15	1433†	(64)	
		15.5	1518	(25)	
CS <sub>2</sub>	Nitric acid.....	16	1425	(76)	
		15	1161	(25)	
CHCl <sub>3</sub>	Carbon disulfide.....	20	1160	(76)	
		15	983	(25)	
CH <sub>3</sub> NO <sub>2</sub>	Chloroform.....	15	1360.5	(14)	
CH <sub>3</sub> O	Nitromethane.....	21.0	1143.2	(14)	
C <sub>2</sub> H <sub>5</sub> O	Methyl alcohol.....	19.0	1264	(64)	
		8.4	1275	(76)	
		23	1160	(105)	
C <sub>3</sub> H <sub>6</sub> O	Ethyl alcohol.....	20.5	1189.4	(14)	
C <sub>4</sub> H <sub>10</sub> O	Acetone.....	0	1152	(64, 105)	
		15	1024	(25, 76)	
C <sub>5</sub> H <sub>12</sub> O	Ethyl ether.....	20.0	1269.8	(14)	
C <sub>6</sub> H <sub>6</sub> Cl	Amyl alcohol.....	17.0	1315.4	(14)	
C <sub>6</sub> H <sub>5</sub> NO <sub>2</sub>	Chlorobenzene.....	17.5	1506.1	(14)	
C <sub>6</sub> H <sub>6</sub>	Nitrobenzene.....	16.3	1170	(76)	
		17	1166†	(25)	
C <sub>6</sub> H <sub>7</sub> N	Benzene.....	20.8	1675.7	(14)	
C <sub>6</sub> H <sub>11</sub> O <sub>3</sub>	Aniline.....	21.5	1202.4	(14)	
C <sub>6</sub> H <sub>14</sub>	Paraldehyde.....	21.0	1111.7	(14)	
C <sub>7</sub> H <sub>7</sub> NO <sub>2</sub>	<i>n</i> -Hexane.....	20.5	1482.0	(14)	
C <sub>7</sub> H <sub>8</sub>	<i>o</i> -Nitrotoluene.....	20.5	1327.2	(14)	
C <sub>7</sub> H <sub>8</sub> O	Toluene.....	21.5	1492.5	(14)	
C <sub>7</sub> H <sub>9</sub> N	<i>m</i> -Cresol.....	21.0	1644.8	(14)	
C <sub>8</sub> H <sub>10</sub>	<i>o</i> -Toluidine.....	21.6	1602.4	(14)	
		20.0	1351.0	(14)	
Aqueous Solutions					
Solute	<i>C</i>	<i>t</i>	<i>V<sub>t</sub></i>	Lit.	
HCl.....	1.207	15.5	1518	(25)	
		16	1455	(76)	
H <sub>2</sub> SO <sub>4</sub> .....	7 %	18.5	1455	(76)	
		19.7	1475	(76)	
		19.6	1380	(76)	
		20.6	1280	(76)	
NH <sub>3</sub> .....	92 %	15	1440	(76)	
		7.3 %	15	1470	(76)
		17.5 %	15	1540	(76)
		23 %	15	1635	(76)
C <sub>2</sub> H <sub>5</sub> OH.....	0.880	16	1663	(25)	
		11 %	4.4	1496	(64)
		95 %	12.5	1241	(25)
		95 %	20.5	1213	(25)
ZnSO <sub>4</sub> .....	8 %	16	1445	(76)	
		30 %	13	1465	(76)
		41 %	17.5	1510	(76)
CuSO <sub>4</sub> .....	1.0663	21.5	1513.0	(13)	
		1.1238	21.5	1538.5	(13)
		1.1615	21.5	1562.3	(13)
FeSO <sub>4</sub> .....	1.104	16.5	1485	(76)	
CaCl <sub>2</sub> .....	1.0661	21.5	1546.9	(13)	
		1.1271	21.5	1601.3	(13)

Aqueous Solutions.—(Continued)

Solute	<i>C</i>	<i>t</i>	<i>V<sub>t</sub></i>	Lit.
CaCl <sub>2</sub> —(Continued).....	1.1942	21.5	1672.0	(13)
	43 %	22.5	1980	(105)
BaCl <sub>2</sub> .....	1.0662	21.5	1503.6	(13)
	1.1256	21.5	1524.4	(13)
NaCl.....	1.1970	21.5	1547.6	(13)
	10 %	15	1470	(25)
	15 %	15	1530	(25)
	20 %	15	1650	(25)
	Conc.	14.7	1661	(64)
	Conc.	18.1	1561	(105)
	1.0662	21.5	1586.1	(13)
	1.1259	21.5	1676.1	(13)
Na <sub>2</sub> SO <sub>4</sub> .....	1.1971	21.5	1784.6	(13)
	5.3 %	18.6	1491	(76)
	6 %	19.4	1474	(76)
	11.7 %	17.3	1508	(76)
	11.8 %	20	1525	(105)
	Conc.	19	1584	(105)
NaNO <sub>3</sub> .....	Conc.	14.7	1528	(64)
	Conc.	15.3	1650	(64)
Na <sub>2</sub> CO <sub>3</sub> .....	Conc.	20.9	1670	(105)
	Conc.	22.2	1594.4	(105)
KOH.....	12 %	15.7	1430	(76)
	19 %	19.1	1580	(76)
KNO <sub>3</sub> .....	29 %	19.7	1620	(76)
	Sat. ¶	14.4	1515	(64)

Ill-defined Liquids

Liquid	<i>t</i>	<i>V<sub>t</sub></i>	Lit.
Gasoline.....	7.4	1395	(64)
Petroleum.....	7.4	1395	(64)
Turpentine.....	15	1326	(64)
	3.5	1371	(64)
	15	1326	(25)
	24	1212	(105)

\* *V<sub>t</sub>* = 1398 + 3.28*t* from 13° to 31° (25).  
† *V<sub>t</sub>* = 1383 + 3.33*t* from 3.9° to 25.2° (64).  
‡ Author calls it "Benzin," does not give formula.  
§ Described as "concentrated;" perhaps saturated was meant.  
¶ Saturated solution.

TABLE 5.—VELOCITY (V) OF SOUND IN NATURAL WATERS

In all oceans, the average vertical velocity for depths of 3.5 to 8.0 km is 1528 to 1529 m/sec; for lesser depths, it is less; values computed from density and adiabatic compressibility by method of Heck and Service (41) may differ by 20 m/sec from the actual value (41). Unit of *V* = 1 m/sec; of depth = 1 m; temperature = *t*, °C.

Water	Depth	Salt	<i>t</i>	<i>V</i>	Lit.
Lake Geneva.....			8.1	1435	(18)
Seine River.....			15	1437	(105)
			30	1528	(105)
			50	1652.2	(105)
			60	1724.7	(105)
Ocean: Horizontal Velocity					
Open ocean.....	13	3 %*	14.5	1503.5	(63)
Block Island Sound, N. Y.....	30	3.35 %	3.0	1453.3	(87)
Long Island Sound, N. Y.....	30		13	1492.3	(29)
Isle of Wight.....		3.51 %	6	1474	(110)
		3.52 %	7	1478	(110)
		3.5 %	16.95	1511	(110)



TABLE 5.—(Continued)

Water	Depth	Salt	$t$	$V$	Lit.
<i>Ocean: Vertical Velocity</i>					
North Atlantic.....	1288			1520	(41)
Caribbean Sea.....	338			1478	(41)
	1771			1486	(41)
Pacific.....	1185			1505	(41)
	2962			1493	(41)
All oceans.....	3500 to 8000			1528	(41)

\* Density at 14.9° = 1.0245 g/cm<sup>3</sup>.TABLE 6.—VELOCITY ( $V$ ) OF SOUND IN SOLIDS

Pure metals; alloys; papers, fabrics, and skins; woods; miscellaneous. Either room temperature or  $t$ , °C. Unit of  $V$  = 1 m/sec.

Metals	$t$	$V$	Lit.	Metals	$t$	$V$	Lit.
<i>Pure Metals</i>				<i>Pure Metals.—(Continued)</i>			
Ag.....	2645	(65)		Pd.....	10 3074	(105)	
	18 2608*	(105)			3257	(65)	
	10 2678†	(105)		Pt.....	(?) 2792	(65)	
	20 2678†	(105)			20 2690	(105)	
	100 2640†	(105)			100 2570	(105)	
	200 2480†	(105)			200 2460	(105)	
Al.....	5105	(65)			18 2688*	(105)	
Au.....	(?) 2082	(65)			10 2736†	(105)	
	10 2112†	(105)		Sn.....	13 2490	(35)	
	20 1743*	(105)			2490	(16)	
	100 1720*	(105)			2640	(65)	
	200 1735*	(105)		Zn.....	13 3681	(35)	
Cd.....	2307	(65)			3699	(65)	
Co.....	4724	(65)		<i>Alloys</i>			
Cu.....	20 3560	(105)		Brass.....	3479	(65)	
	100 3290	(105)			3617	(54)	
	200 2950	(105)			3235¶	(105)	
	(?) 3825	(65)		Steel.....	<i>See above, Fe</i>		
	3984	(16)					
Fe.....	20 5130	(105)					
	100 5300	(105)					
	200 4720	(105)					
	(?) 5016	(65)					
	15 4913	(105)		Zn-Sn.....	0 3681	(35)	
Steel.....	18 4982†	(105)		(13°C, $x$ atoms	1 3338		
	10 4940§	(65)		Sn to 5	2 3195		
	5093§	(54)		atoms Zn)	3 3100		
	20 4990	(105)			4 3032		
	100 4920	(105)			5 2980		
	200 4790	(105)			6 2940		
Mg.....	4602	(66)			7 2898		
Ni.....	4973	(65)			8 2850		
Pb.....	1322	(65)			9 2785		
	18 1229*	(105)			10 2710		
					∞ 2490		

*Papers, Fabrics, Skins (66)*

The velocity in a given specimen depends upon the tension. All the membranous materials were cut in strips 15 mm wide ((66), p. 575), but neither their thicknesses nor the diameters of the cords are stated. The velocity was observed while the strip, or cord, carried a longitudinal load of  $w$  kg.

Material	$w$	$V$
Cord: Cotton.....	1	1425
Linen.....	1	1815
	2	1942
Oilcloth.....	1	559

*Papers, Fabrics, Skins.—(Continued)*

Material	$m$	$V$
Paper: Blotting.....	0.5	1627
Parchment.....	0.7	2198
Silvered.....	0.6	2575
Straw.....	0.5	1617
Tissue.....	0.1	1989
Tracing.....	0.7	2278
Writing.....	0.9	2167
Parchment: French.....	2	1860
German.....	1.5	1636
Satin ribbon.....	1	2015
Sheepskin.....	0.1	471

*Woods*

$V_{||}$ ,  $V_r$ ,  $V_c$  = velocity parallel to grain, radial velocity, circumferential velocity; unit = 1 m/sec.  $d$  = density; unit = 1 g/cm<sup>3</sup>.

Wood	$d$	$V_c$	$V_r$	$V_{  }$	Lit.
Ash.....		1260	1390	4670	(105)
	0.542			4272	(46)
	0.562			3657	(46)
Beech.....		1415	1840	3340	(105)
				3412	(66)
Cedar.....	0.455			3975	(46)
	0.465			4926	(46)
Cherry.....				4410	(46)
Elm.....		1013	1420	4120	(105)
Fir.....				5256	(86)
				4179	(66)
Fir: Red.....				4274	(46)
White.....				4640	(46)
Mahogany.....				4135	(46)
Maple.....				4110	(105)
Oak.....				3381	(66)
Oak: Red.....				4180	(46)
White.....				4316	(46)
Pine.....				3320	(105)
Poplar.....				4280	(105)
Sycamore.....				4460	(105)
Walnut.....				4781	(46)

*Miscellaneous Materials*

{ 430 indicates that  $V$  ranges from 430 to 530 m/sec  
530

Material	$t$	$V$	Lit.
Beeswax.....	15	880	(86)
	16	863	(103)
	28	450	(86)
Brick.....		3652	(16)
Caoutchouc, vulcanized: Black.....	0	54	(31)
	50	30.7	(31)
Red.....	0	69.3	(31)
	57	36.6	(31)
	70	33.9	(31)
Gray.....	0	43.2	(31)
	45	32.3	(31)
Tubing.....		27	(86)
Very hard...		150	(86)
Cork.....		430	(86)
		530	
Ebonite.....	15	1573	(15)
Gelatin.....		1364	(44)
		1626	
Glass.....		5991	(86)
		5060	(54)
	16	5202	(103)



Material	<i>t</i>	<i>V</i>	Lit.
Glass: Soda.....		5000	**
		5300	
Flint.....		4000	**
Granite.....		3950	(37)
Ivory.....		3013	(17)
Marble.....		3810	(37)
Paraffin.....	6.1	1522	(84)
	16	1304	(103)
	17.3	1419	(84)
	21.6	1325	(84)
	25.2	1192	(84)
	27.8	1035	(84)
	29.3	851	(84)
	30.5	748	(84)
	32.9	470	(84)
	35.3	250	(84)
Rock ( $\pm 700$ m/sec).....		2500	(4)
Sand ( $\pm 600$ m/sec).....		2000	(4)
Sealing wax.....		1320	(86)
Shellac, white.....		1320	(86)
	8.7	1009	(84)
	26.3	869	(84)
	40	762	(84)
Slate.....		4510	(37)
	4.9	1517	(84)
Spermaceti.....	33.1	1091	(84)
Stearin.....	16	1378	(103)
	16.1	1354	(84)
	33.6	1181	(84)
	48.2	911	(84)
Suet.....	18	460	(86)
Tallow.....	16	390	(103)
Tuff.....		2850	(37)
Wax ( <i>v.</i> Beeswax).....			

\* Soft.  
† Hard.  
‡ Mild steel.  
§ Blue tempered steel.

|| Cast steel.  
¶ Unannealed.  
\*\* Various observers.

The velocity of sound in a gas contained in a tube depends upon the heat conductivity of, and the velocity of sound in, the material of the tube, upon the viscosity and the heat conductivity of the gas, upon the character of the inner surface of the tube, upon the rate and the direction at which heat and vibrations are transferred between the tube and external objects, upon the pitch and intensity of the sound, and upon the thickness and diameter of the tube (27, 32, 42, 51, 69, 72, 77, 78, 81, 93). If the inner surface of the tube is smooth, and if the transfer of energy to external objects is negligible, the velocity is given by the expression  $V = V_{\infty}(1 - K/D\sqrt{n})$ , where  $D$  = diameter,  $n$  = pitch,  $K$  depends upon the properties of the tube and gas, and  $V_{\infty}$  = velocity in an unlimited volume of the gas. Under other conditions, this expression may be multiplied by a quantity depending upon the material and dimensions of the tube, and  $K$  may involve  $D$  and  $n$ . Some observers (77, 81) claim  $V = V_{\infty}(1 - K/Dn^{3/2})$ , another (108) concludes that the exponent of  $n$  is 0.53.

For air in iron and in porcelain (72, 93),  $D \leq 4$  cm,  $n = 500$ , 600, and "explosion,"  $V$  differs but little from its value in free air; *see also* (99). When other observations are represented by the following equations,  $\delta$  has the values tabulated:

Air in glass,  $D > 0.6$  cm (54, 58, 69, 81),  $V = 331.0(1 - 0.501/D\sqrt{n})(1 + \delta)$ .

Unit of  $\delta = 0.001$ ; of  $D = 1$  cm; of  $n = 1$  double vibration per sec.

Air in glass									Air in brass			
$n$	256	320	384	512	1023	1850	2482	5550	$n$	256	384	512
$D$	$\delta$								$D$	$\delta$		
0.101			+3	- 8					0.099		0	0
0.151			+2	+ 6					0.148		-25	+16
0.34		+32		+35					1.17	0		
0.68							-2		1.95	-1		
0.93	+2			+ 2	-0				3.25	+0		
1.3						+5		+5	5.41	+0		
1.71	+1			0	-1				8.82	0		
2.80	0			- 0	-2							
5.5								+7				

CO <sub>2</sub> in glass						H <sub>2</sub> in glass			
$D$	0.21	0.35	0.53	1.02	2.11	0.35	0.53	1.02	2.11
$n$	$\delta$					$\delta$			
705		-0	-1	-3	-1				
1943	+4	0	-2	-3	+4				
3755	+6	+4	-1	-3	+5	-0	+1	-0	+9

(For a key to the periodicals see end of volume)

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## LITERATURE REFERENCES

## LITERATURE REFERENCES

In all literature references cited in International Critical Tables the name of the journal or publication is indicated by means of a *Key number* corresponding to the list given below. The numbers which follow this key number in a literature citation are, in the order named: (1) the volume, (2) the page, and (3) the last two figures of the year. Thus 64V, 31: 253; 22, indicates Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, page 253, 1922. Series numbers are not given. Key numbers referring to books and other non-serial publications are preceded by the letter *B*, and the volume number is given in roman numerals. Thus B10, IV: 191; 18, indicates Doelter, Handbuch der Mineralchemie, page 191 of Vol. 4 of the 1918 edition. The Key number *O* is used to indicate "private communication from."

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## KEY TO THE PERIODICALS

Data regarding the libraries which receive many of these periodicals may be found through the following sources:

United States and Canada: "Periodicals Abstracted by Chemical Abstracts, 1926" (Chemical Abstracts, Ohio State Univ., Columbus, Ohio); "Union List of Serials in the Libraries of the United States and Canada, 1927" (H. W. Wilson & Co., New York City); "A Catalogue of Scientific Periodicals in Canadian Libraries, 1924" (McGill Univ., Montreal, Canada).

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5. Proceedings of the Royal Society (London). A. Mathematical and Physical Sciences.
- 5B. Proceedings of the Royal Society (London). B. Biological Sciences.

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Le nom du journal ou de la publication de toutes les références bibliographiques citées dans les Tables Critiques Internationales est indiqué au moyen d'un *nombre-clé* correspondant à la liste donnée ci-dessous. Les nombres qui suivent ce nombre-clé dans un renvoi bibliographique indiquent dans l'ordre suivant: (1) le volume, (2) la page, et (3) les deux derniers chiffres de l'année. Ainsi 64V, 31: 253; 22, indique Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, page 253, 1922. Les numéros des séries ne sont pas donnés. Les nombres-clés se rapportant à des livres ou à des publications non périodiques sont précédés de la lettre *B* et le numéro du volume est donné en chiffres romains. Ainsi, B10, IV: 191; 18, indique Doelter, Handbuch der Mineralchemie, page 191 du volume 4 de l'édition de 1918. Le nombre-clé *O* est employé pour indiquer "communication privée de."

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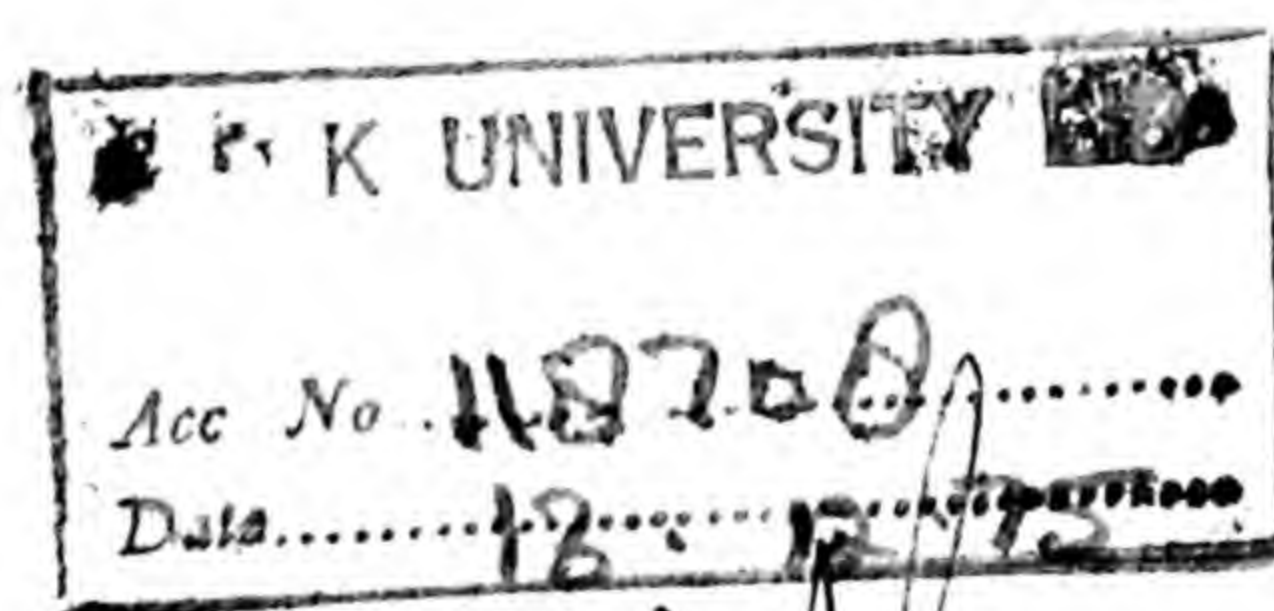
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338. Researches of the Electro-Technical Laboratory (Tokyo).
339. American Journal of Mathematics.
362. Chemické Listy pro vedu a průmysl.
365. Bureau of Standards, Circulars.
384. Le génie civil (Paris).
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417. Iron and Steel Institute, Carnegie Scholarship Memoirs.
420. Bulletin de la société d'encouragement pour l'industrie nationale.
422. American Machinist.
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428. Repertorium für Experimental-Physik für physikalische Technik für mathematische und astronomische Instrumentenkunde. (*Before 1867 was* Repertorium für physikalische Technik für mathematische und astronomische Instrumentenkunde; *also known as* Carl's Repertorium.)
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